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Effect of Age on the Operating and Support Costs of CG-47 Class Cruisers

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14. ABSTRACT
To gain insight into the operating and support costs of major U.S. surface combatants, IDA looked at trends for the CG-47 class cruiser. This paper presents evidence of the dependence of O&S cost on age and explores cost trends over time. Since the major purpose of the trend analysis was to measure the effects of the recent changes in maintenance policy, we discuss the goals of these changes. We also performed a multiple regression analysis to see how O&S costs depend on age and other cost drivers for the CG-47 class and for all the major surface combatants taken together (to see if the dependence of CG-47 on age is due to the young age of the ship class). Finally, the paper contains results of a quantitative analysis of casualty report (CASREP) trends over time. Our principal finding is that for the CG-47 and other combatants as well, O&S costs do not show the consistent increase with ship age we would expect. Also, CASREP incidence is increasing because of a few problem pieces of equipment.

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PREFACE

The Institute for Defense Analyses (IDA) prepared this paper for the Office of the Director, Program Analysis and Evaluation, under a task titled "The Effects of System Aging on Operating and Maintenance Costs." The task objective was to study a series of military aircraft and ships to document the relationships between system age and operating and support costs. (The study was broadened to include personnel costs, and thus total O&S costs, after the task was entitled.) This paper partially fulfills that objective by exploring the relationships between the age and operating and support costs of the CG-47 class cruiser.

William L. Greer, Stanley A. Horowitz, and Lance Roark of IDA were the technical reviewers for this paper.

We obtained the Visibility and Management of Operating and Support Costs (VAMOSC) cost and yard data on which our analysis is based from the Naval Center for Cost Analysis (NCCA). We are especially in debt to Colleen Adamson of NCCA for her many discussions with us throughout the analysis.

Joan Lindner at Inventory Control Point (ICP), Mechanicsburg, Pennsylvania, was instrumental in helping us obtain the casualty report (CASREP) data. Robert Lindner of the Commander, U.S. Surface Forces, Atlantic (COMSURFLANT) staff was especially instrumental in helping us understand Atlantic Fleet maintenance policy and operations.

In addition, we benefited from conversations with the following people involved with the CG-47s: the Aegis Program Manager (PMS 400F); Office of the Chief of Naval Operations (OPNAV) Supportability, Maintenance and Modernization Division (N43); Naval Sea Systems Command (NAVSEA) Assistant for Maintenance Process Improvement (05N); the COMSURFLANT staff at Norfolk, Virginia; Supervisor of Shipbuilding (SUPSHIP) at Portsmouth, Virginia; and the Commander, Naval Surface Group Two (COMNAVSURFGRU TWO) staff at Pascagoula, Florida.

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I. INTRODUCTION AND SUMMARY

A. POLICY ISSUES

The Office of the Secretary of Defense (OSD) and the Navy have some decisions to make regarding the force levels of major U.S. surface combatants. Among these are the buy versus renew decisions. How long should the existing ships be maintained? How many new ships should be bought? When should they be bought? And (of lesser importance) how much money should be set aside in future-year Operating and Support (O&S) budgets to operate and support existing ships?

Such decisions depend heavily on the extent to which existing combatants are becoming more costly to operate and maintain with age. Also of interest is whether recent changes in Navy maintenance policy are having the intended effect of reducing O&S costs or moderating their increase with age.

B. QUESTIONS FOR ANALYSIS

OSD asked IDA to help with these problems by addressing several questions. The quantitative part of our analysis analyzed historical costs to answer the following questions:

- What is the effect of ship age on the O&S costs of the CG-47 (Ticonderoga) class of guided missile cruisers?[1]
- Have the CG-47's maintenance costs fallen with changes since the 1980s in the Navy's maintenance policies mandated by Chief of Naval Operations (CNO) directives?[2]

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1 Although the task order asked for analysis of the older DD-963 destroyer, this was changed to the newer CG-47 class in later discussions with the sponsor. The reason was OSD's feeling that the data for the newer class would be more reliable. For comparison, we performed some analysis of the other surface combatants—the DDG-51 destroyer, DD-963 destroyer, and FFG-7 frigate.

2 In brief, these policies are intended to shift some of the maintenance workload from the infrequent and long shipyard availabilities (periods of repair and modification) scheduled by the Office of the Chief of Naval Operations staff to the more frequent and shorter availabilities scheduled by the class Type Commanders.

OSD also asked us whether the historical data were good enough (that is, do they offer appropriate metrics) to support reliable analysis. Chapter VII of this paper offers some discussion of this issue.

C. PLAN OF ANALYSIS

To gain insight into the behavior of O&S costs, we looked at trends in average O&S cost and time in maintenance, first with respect to ship age, our principal focus, and then with respect to calendar year.

Chapter II of this paper gives some background information on the CG-47's shipbuilding program, explains our sources of data, and summarizes average O&S costs for the CG-47 class from 1984 to 1999.

Chapter III presents our evidence of the dependence of O&S cost on age, and Chapter IV explores cost trends over time. Since the major purpose of the analysis of maintenance trends was to measure the effects of the recent changes in maintenance policy, we present in Chapter IV a somewhat extended discussion of these policy changes before explaining the analysis of the time trends of maintenance cost.

In Chapter V, we present a multiple regression analysis to see how the O&S costs depend on various cost drivers for the CG-47 class and all the major surface combatants taken together.

Chapter VI contains a quantitative analysis of Casualty Report (CASREP) trends over time.

Chapter VII presents our findings regarding the dependence of CG-47 O&S costs on age, the effect of recent changes in maintenance policy on CG-47 costs, and changes in CG-47 reliability over time and as a function of age. These findings are summarized in the section that follows. We also give our thoughts on the adequacy of Navy data and management information systems for the type of analysis we conducted.

D. SUMMARY OF FINDINGS

1. Dependence of CG-47 O&S Costs on Age

The O&S costs of the CG-47 fail to show the consistent rise with age that we would expect. Rather, they exhibit a peaking behavior: The average annual O&S cost per ship rose from $25 million to $35 million as the ships approached 8 to 10 years of age, but then fell back to $25 million by age 17, the maximum age of our data.

Because this finding is both important for policy purposes and counter-intuitive, we searched for possible reasons for the peaking phenomenon. None of them proved entirely satisfactory.

The first possibility regarding our negative finding as to age is that the fall-off in O&S cost is due to the lower O&S costs of the first five CG-47s—those that reached the oldest age during the period. Those ships lack the more capable Vertical Launch System (VLS) and other block improvements and are being used preferentially for less arduous missions, such as drug interdiction and exercises with South American navies rather than deploying with carrier battle groups. However, we found that the O&S costs of the VLS ships also experienced a fall-off at older ages.

A second possibility concerns the question of whether the CG-47s might still be too young for age to have taken its toll, and that the older naval surface combatants might show a consistent upward trend. However, we found the same peaking behavior when we performed a statistical analysis of all the major surface combatants taken together.

Another possibility relating to repair cost is that Navy maintenance officers might have been cutting back too much on insurance repairs in response to CNO directives to move from the less frequent CNO-scheduled availabilities to the shorter but more frequent Type Commander (TYCOM)-scheduled availabilities. A counter to this, however, is that Surface Force, Atlantic Fleet (SURFLANT) has not found a rise in their spending for emergent problems.

Finally, there is a possibility that the Navy might have been cutting back on CG-47 modernization spending during the period of analysis as a holding position, either in anticipation of receiving additional funds for the CG-47 conversion program, or to avoid spending money in the event it has to decommission the ships.

If this is, in fact, occurring, the implication is that the peaking of maintenance, and thus total O&S cost is at least partly caused by the idiosyncrasies of Navy budgeting. Our results do not, therefore, argue against the expectation that intrinsic repair costs must eventually show a consistent rise. The principal finding of our study, therefore, is that either there has been no consistent increase in O&S costs with age during the time period of our analysis—perhaps because the CG-47s are not yet old enough—or that the effect of aging have been masked by budgeting idiosyncrasies.

Our analysis does, however, suggest that depot maintenance cost (repair plus modernization) is the driving force behind the behavior of total O&S costs, and that this area of cost should be analyzed further.

2. Effect of Recent Changes in Depot-level Maintenance Policy on CG-47 Costs

Results are mixed on this issue. There has been the expected shift in maintenance costs and time from CNO- to TYCOM-scheduled availabilities, but this has been accompanied by unexpected increases in total maintenance costs and times. Ship operators and maintenance personnel still have some incentives to make repairs in yard periods when they occur (strike while the iron is hot), and may therefore frustrate, to some extent, the implementation of the policy changes mandated by the CNO. Second, Fleet personnel have told us that the policy changes are, in fact, in the process of implementation; we may be observing the initial inefficiencies of adopting new strategies.

Third, implementation may have already occurred and saved money to a significant extent, but costs have nevertheless risen on balance because of other factors (i.e., costs would have risen more in the absence of the policy changes). Final evaluation of the maintenance policies must wait for further data.

3. Changes in Reliability Over Time and as a Function of Age

In addition to analyzing trends in O&S costs, we analyzed data on the incidence of ship Casualty Reports (CASREPs) to see how reliability changed over time and as a function of age. (Incidence measures the average number of new reports per ship per year, not the number of actions that are still open.)

We focused on the C-3 and C-4 CASREPs, the most serious ones involving major degradation or loss of a primary mission. The effect of age was dramatic: a four-fold increase of average annual incidence per ship from 5 to 20 per year by age 14. The trend over calendar time showed a much smaller rise, from average annual incidence of 3 to 6 per ship per year by 1999. (The rise with age is diluted in the trend over calendar years: all 27 guided missile cruisers were commissioned by the time the first ships reached 14 years, and only the first 3 cruisers reached age 14 by 1999, the end of our data.)

A closer look at the experience of individual ships indicated a consistent explanation for both these observations. The lead ship of the class, the CG-47 hull, had an especially high incidence immediately after commissioning, and things became worse as both it and the CG-48 and CG-49 grew in age.

The rise at age 14 was driven by problems with a relatively small number of equipment types; but the Navy has a well-managed and high-level Top Management Attention–Top Management Issues (TMA-TMI) program to deal with these problems.

II. BACKGROUND

A. CG-47 CLASS

The CG-47 class of guided missile cruisers comprises 27 ships (CG-47 through CG-73) commissioned between calendar years 1983 and 1994 (Figure II-1). Of that total, 9 are homeported in Norfolk, Virginia; 2 in Mayport, Florida; 3 in Pascagoula, Mississippi; 7 in San Diego, California; 3 in Pearl Harbor, Hawaii; and 3 in Yokosuka, Japan. Ingalls Shipbuilding built 19 of the ships and Bath Iron Works built the other 8.

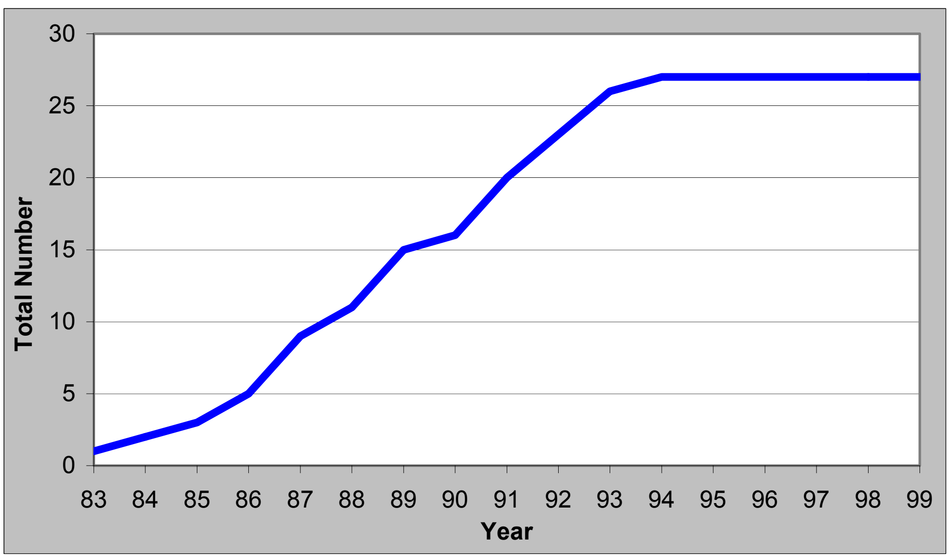

Figure II-1. CG-47 Class Cruiser Building Program

An important point in understanding the costs of these ships is that CG-47 through CG-51, which were commissioned in 1983 through 1987, lack the Vertical Launch System (VLS) and other system upgrades built into later baselines, or blocks.[1] These ships are therefore less complex. Four of these non-VLS ships—three stationed in Pascagoula and one in San Diego—perform less arduous duty involving drug interdiction and annual

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1 The five ships in 1986 in Figure II-1 include the CG-52. The CG-51 was not built until 1987.

UNITAS (Spanish for *unity*) exercises with South American nations. The remaining non-VLS ship is stationed in Japan, where it performs normal battle group operations.

B. DATA SOURCES

We obtained the O&S costs from the VAMOSC Ship Database managed by the Naval Center for Cost Analysis (NCCA). VAMOSC stands for Visibility and Management of Operating and Support Costs. The database contained 21,000 data points for the CG-47s, comprised of 80 O&S cost categories for the 27 hulls over the 16-year period 1984 to 1999. (All ships were not present in all years.) VAMOSC ship costs are compilations of data from approximately 55 different sources.

The O&S costs are the sum of the following appropriation titles: Operations and Maintenance, Navy (O&MN); Military Personnel, Navy (MPN); Other Procurement, Navy (OPN); and Weapon Procurement, Navy (WPN). The Ship Database does not include those costs for shipboard weapon and sensor systems such as the Aegis radar that are funded by the systems' program managers (PMs). These and other costs are reported in the VAMOSC Shipboard Systems Report, but not by hull. They were thus omitted from our analysis.

The depot maintenance times are taken from VAMOSC Depot Availability Data, which list start and completion dates of 700 maintenance periods.

The figures on CASREP incidence were obtained from the Navy's Inventory Control Point (ICP) at Mechanicsburg, Pennsylvania. The figures give the numbers of new CASREP starts in each fiscal year.

C. COST SUMMARY

Table II-1 summarizes the average O&S costs over the entire period of analysis, 1984 to 1999, in millions of FY 2001 dollars. Except where indicated otherwise, all the remaining costs in the study are average annual costs per ship in each fiscal year, in undiscounted constant FY 2001 dollars. Although the CG-47 was commissioned in January 1983, our cost data and analysis start in FY 1984, the first complete fiscal year for the costs.

We spent the most time on the cost components in red. We will present our analysis of these costs graphically, starting first with their dependence on age in Chapter III, the principle object of the analysis. To gauge the effect of changes in maintenance policy over time, we present graphs of time trends in Chapter IV.

Table II-1. Average Annual O&S Cost per Ship, 1984–99

	Cost per Ship (FY01 $M)
Total O&S	29.7
Unit (Organizational Level)	21.9
Personnel	12.0
Material	9.2
POL (fuel underway, fuel not underway)	3.6
Repair parts and repairables	2.7
Supplies	0.5
Training expendable stores (replacement ammunition)	2.4
Purchased Services (printing/reproduction, ADP, communications, etc.)	0.7
Intermediate-level maintenance	0.4
Depot-level maintenance	6.3
Repair during CNO-scheduled availabilities	2.0
Repair during TYCOM-scheduled availabilities	0.7
Modernization (Fleet Modernization Program)	3.2
Other depot-level repair	0.4
Other O&S (training, publications, ETS, ammunition handling)	1.2

Notes: Red denotes the main focus of our analysis. The total does not sum exactly due to rounding.

In both cases, we start at the most aggregate level (total O&S) and work our way down to component costs in hopes of isolating the reasons for the changes in O&S cost. In cases where we lacked a definitive analysis, we offer thoughts derived from discussions with members of the Fleet.

Here are some points to remember in interpreting the graphs. First, as mentioned previously, the first five CG-47s did not receive (and were not backfitted with) the VLS and some of the other improvements given to following ships. These less-complex ships are thus the ones represented at the high end of the age graphs (ages 14 and up), and also at the low end of the year graphs (before FY 1987). Because the number of ships falls to one as these end points are approached, these figures have less statistical significance. We will mention these points in discussing results as we go.

There is a slight inconsistency in the analysis of the O&S and CASREP data. Although the O&S costs are reported starting in the first complete fiscal year after commissioning (FY 1984), the CASREP data are reported as of the first calendar year (FY 1983). The difference has no effect on the results.

Finally, several points of terminology. “Total” cost refers throughout to a sum over cost components, not years. All cost figures are averages over ships by year, and (as Table II-1 indicates, “unit” cost refers to organizational-level cost, not cost per unit. These are the direct costs of operating ships.

III. DEPENDENCE OF O&S COSTS ON AGE

A. TOAL O&S COST

Figure III-1 depicts the following principal result of this analysis: Average O&S cost per ship does not consistently rise with age. This is demonstrated statistically by the fact that a quadratic regression (second degree)[1] fits better than a linear one.[2] There is a huge difference between the values of R^2, which indicate the fraction of the variation in cost (the dependent variable) explained by the variation in ship age (the independent variable).

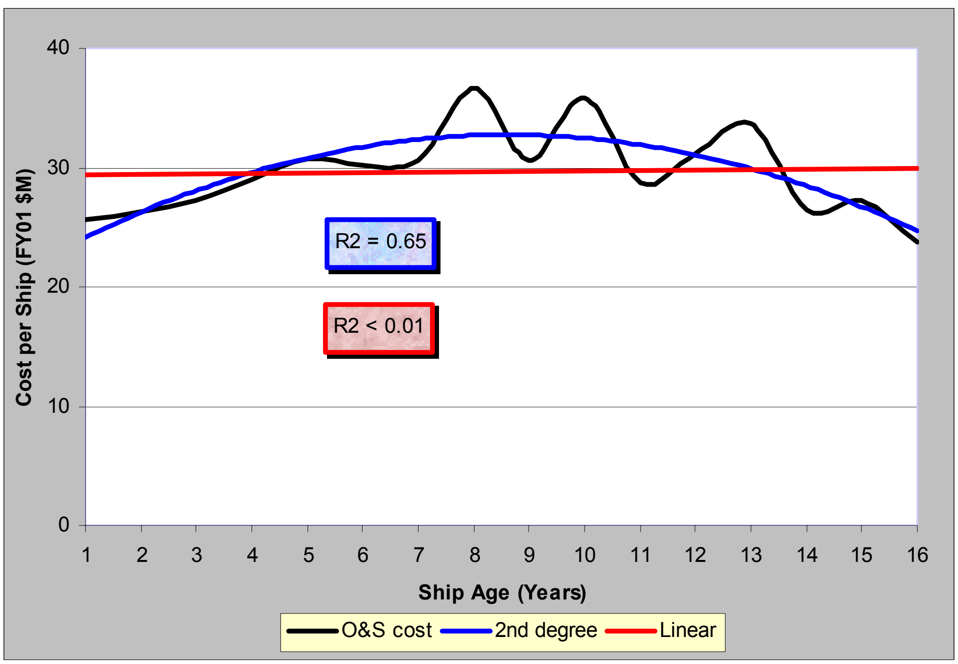

Figure III-1. Average O&S Cost per Ship

There is no indication of the well-advertised "bathtub" behavior—a fall-off in cost after a short period of infant mortality followed by a long period of fairly constant

1 Cost = $a + b(age) + c(age^2)$

2 Cost = $a + b(age)$

costs and a final rise in cost as ships reach old age. (*Infant mortality* is a term in reliability analysis for failures occurring early in life because of design, manufacturing, and material flaws.) It is possible that the CG-47 class fails to show the bathtub behavior because it is still too young—a maximum of 16 years. However, a regression analysis of all four major classes of surface combatants (the much older FFG-7s and DD-963s, as well as the newer CG-47s and DDG-51s) also fails to exhibit the bathtub behavior.

Another possibility is that we don't observe the bathtub because of our focus on O&S costs alone. The bathtub model implicitly includes the frequently high costs of post-shakedown availabilities, remedial costs immediately following construction, which we neglect because they are funded from a procurement account—Shipbuilding and Conversion, Navy—not O&S.

The marked fall-off with age in the previous graph could be due not to an intrinsic effect of age, but to the fact that the Navy might be spending less money supporting the older non-VLS ships because of their reduced capability. To examine this possibility, we looked at the costs of the VLS ships alone. (These ships reached at most 12 years of age by the end of our data in 1999.) As Figure III-2 shows, these costs do not exhibit the distinct peaking (up-and-down) behavior of the last graph—the linear and quadratic equations fit more closely than before. However, the value of R^2 for the quadratic relationship is still substantially higher than for the linear form, so the data fail to show a definite increase of cost with age.

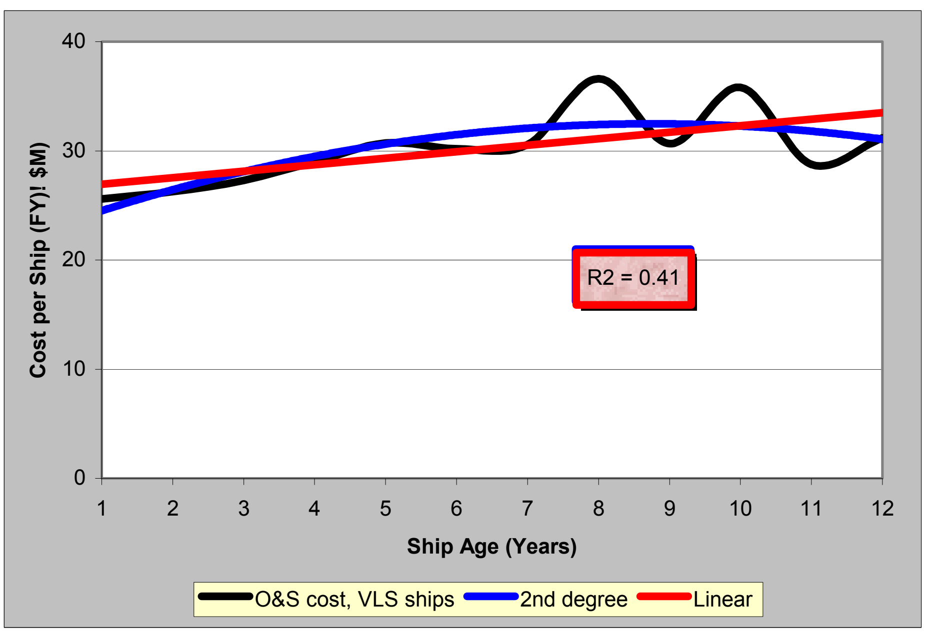

Figure III-2. Average O&S Cost per Ship: VLS Ships Only

We thus conclude that total CG-47 O&S costs per ship rise during the first 8 to 10 years of ship life and fall thereafter. This is true both for VLS and non-VLS ships.

B. UNIT COSTS

Figure III-3 shows that unit (organizational-level) cost is the major contributor to total O&S cost, but the *fluctuations* in O&S cost are driven by depot maintenance. The fall in cost at the older ages may be due to reduced maintenance of the non-VLS ships.

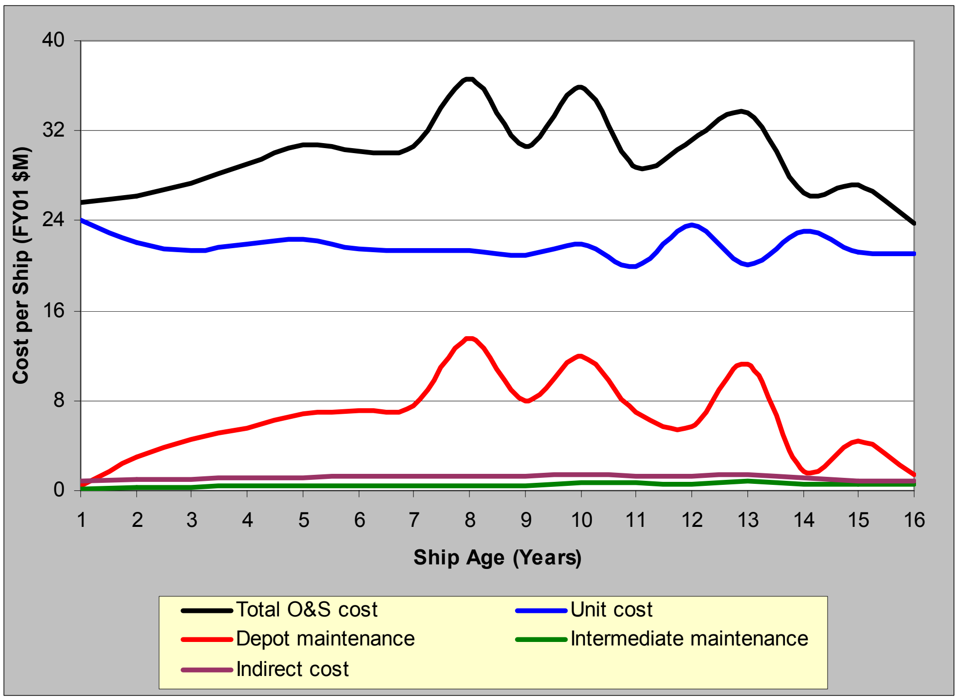

Figure III-3. Average O&S Component Costs per Ship

The major determinants of unit cost, which together comprise 92% of the total, are personnel, fuel underway, replacement ammunition, and repair parts and repairables (Figure III-4). The figure does not show unit maintenance cost because VAMOSC does not report this cost directly. It can be calculated, however, by multiplying VAMOSC maintenance labor man-hours by a suitably chosen average wage rate and then adding unit material costs. We will later mention an analysis by the Naval Center for Cost Analysis that makes this calculation. We did not because total unit cost shows no trend with age to be explained.

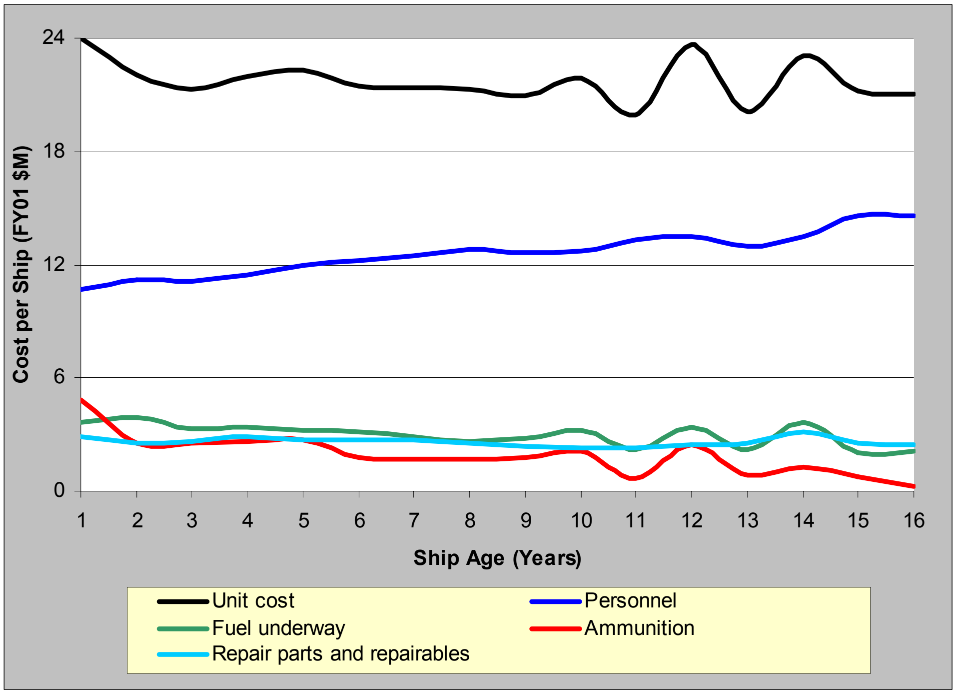

Figure III-4. Average Unit Component Costs per Ship

1. Personnel

The upward trend in personnel cost (Figure III-5) is hard to explain, given that crew size *falls* with age and military pay rises only slightly. (Military pay, as all other costs in this study, is measured in constant FY 2001 dollars.) A small part of the difference is due to an accounting change the Navy made in FY 1998. Since this change occurred at a particular point in time, the effect is better shown in our discussion of time trends presented in Chapter IV of this paper.

2. Petroleum, Oil, and Lubricants (POL)

Our discussion of POL (shown in Figure III-6) focuses on the cost of fuel underway, which is 87.6 % of total POL costs (POL is 99.6% fuel, of which 88.0% is fuel underway).

To understand the trend and fluctuations in underway fuel cost, we obtained data on its factors: the annual number of steaming hours underway (approximately 2,900, a third of the 8,800 total hours per year), the number of barrels per steaming hour underway (which varies greatly with ship speed, but is typically about 30 barrels for the CG-47s throughout the period), and the cost per barrel ($45 is an average estimate for the CG-47 ships during FY 1984-99). We converted the data on barrels per steaming hour underway and fuel price to indices for purposes of graphing.

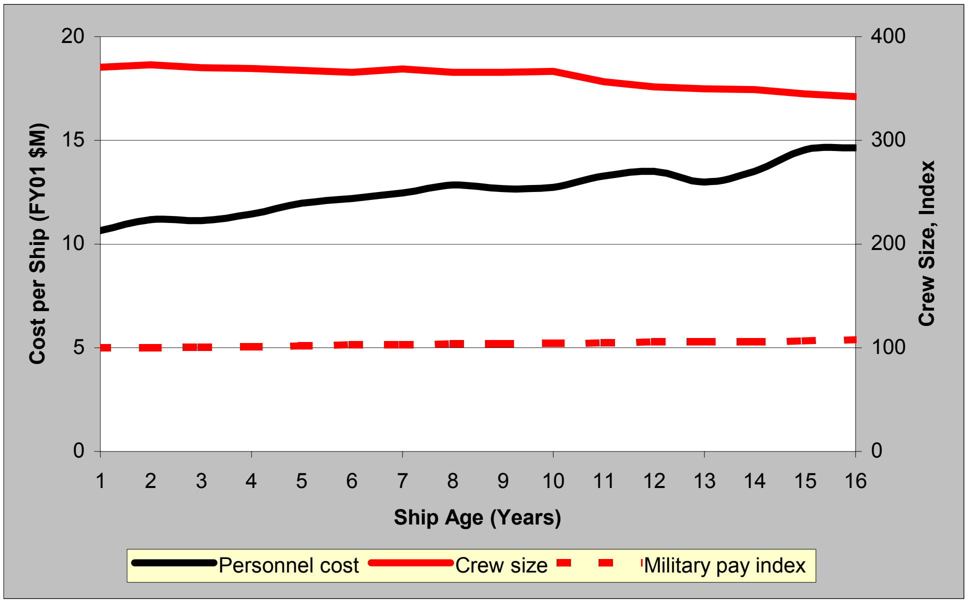

Figure III-5. Average Personnel Cost per Ship

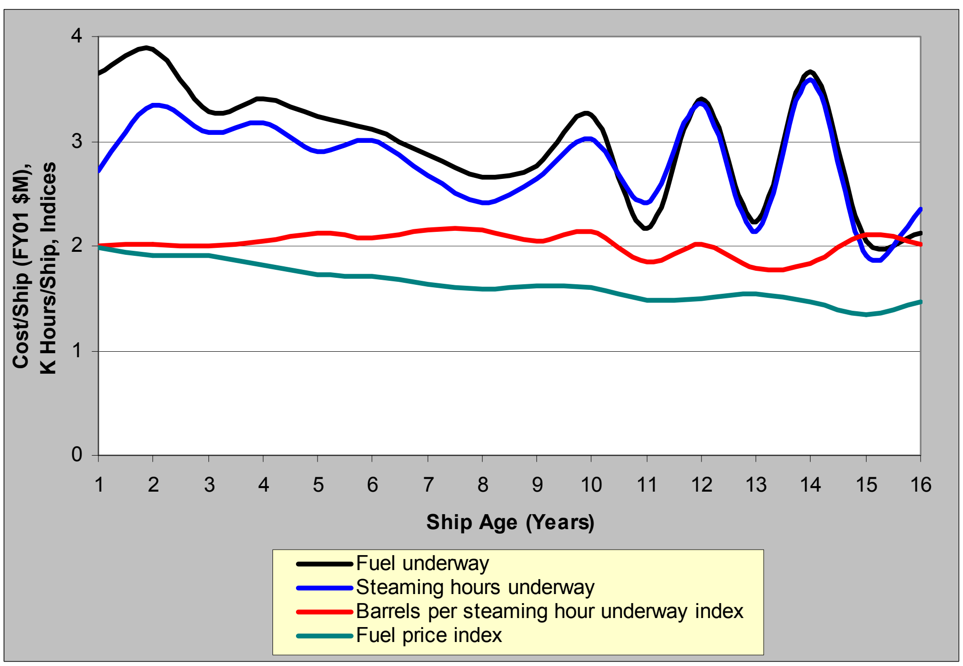

Figure III-6. Average Fuel Underway Cost per Ship

The substantial decline in fuel underway cost seems to be fully explained by large parallel declines in steaming hours underway and fuel price. There is no significant change in barrels per steaming hour.

The wide fluctuations in steaming hours underway are related to the ship maintenance cycle. Ships may burn some fuel when they receive maintenance at the pier, but certainly not when they are in major maintenance availabilities. We found that steaming hours underway is negatively correlated with depot-level maintenance cost, as expected, but the magnitude of 0.28 is surprisingly low.

3. Ammunition

Ammunition usage (Figure III-7) was high during the early years following the commissioning of each ship because weapons are fired as part of personnel training and weapon testing. (The figure shows replacement ammunition, not initial loadout. It is 99% of the major component of training expendable stores.)

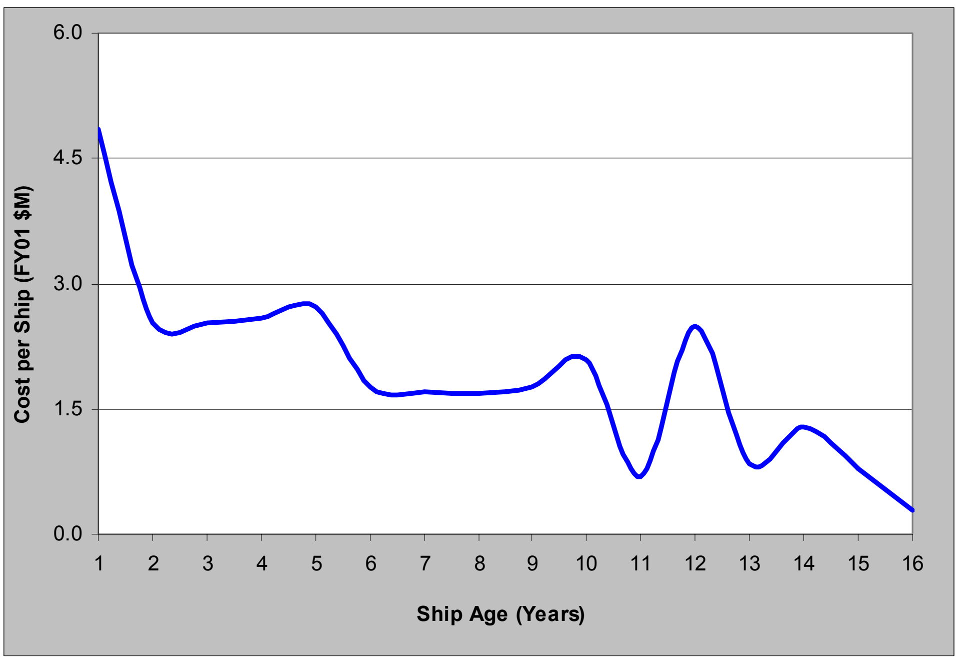

Figure III-7. Average Ammunition Cost per Ship

4. Maintenance

Figure III-8 shows average depot maintenance cost and time per ship. The rapid fluctuations are no doubt due to the periodic maintenance cycle. (We are discussing total time in all maintenance availabilities per ship each year, not average time spent in the various availabilities.)

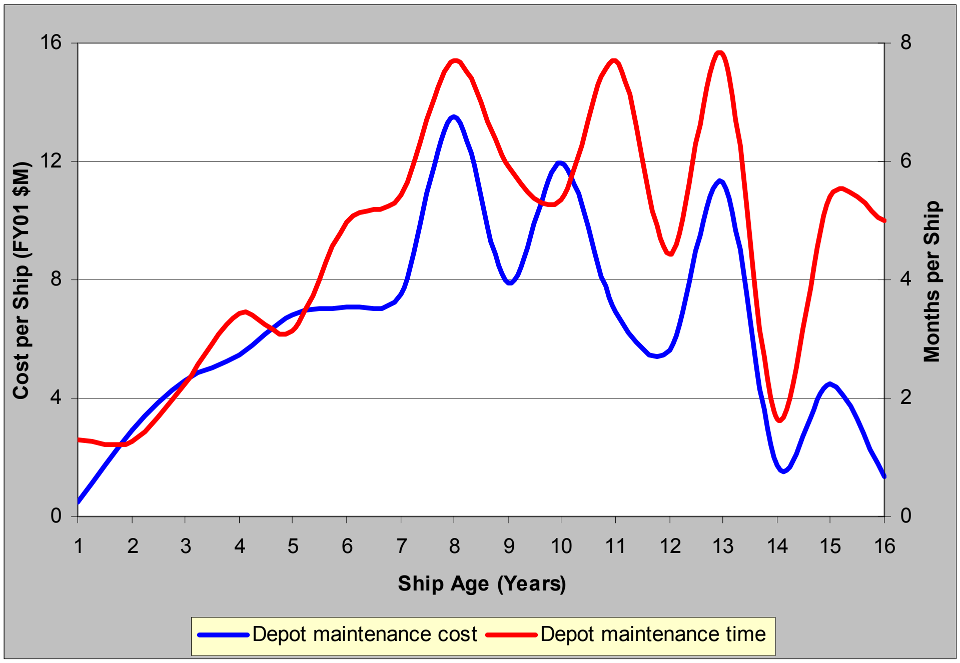

Figure III-8. Average Depot Maintenance Cost and Time per Ship

Some suggest that maintenance cost may be more closely related to operational time (i.e., steaming hours) than to calendar time. We incorporated the effect of steaming hours in the previous explanation of fuel cost, and consider its contribution to total O&S in the regression analysis in Chapter V.

The up-and-down behavior, which is also exhibited by total O&S cost, shown previously, gives no indication of either the bathtub model or an increasing trend with age. The lack of a bathtub might, again, be due to a lack of infant mortality because the VAMOSC O&S data do not report the early post-shakedown availability costs funded by procurement accounts. The lack of a rise with age might be due, as we said previously, to the relatively young age of the CG-47 class. (Also, the non-VLS ships receive free Mk-26 repair parts from de-commissioning ships.) It is also true that Navy spending for maintenance depends on budget constraints and the need for maintenance across the Fleet, not just the needs of the CG-47 class. We tried to account for these possibilities in the regression analysis of total O&S cost discussed in Chapter V.

Finally, the fall in maintenance cost for the older ships might be due to the use of four of the five non-VLS ships for less-demanding missions such as counter-drug interdiction and treaty exercises, rather than deploying with carrier battle groups. Three of the five non-VLS ships are homeported in Pascagoula (CG-47, -48, and -51) and spend 4 months per year in counter-drug operations and 2 months on UNITAS exercises with

South American navies. On the West Coast, the CG-50 stationed in San Diego also performs counter-drug operations. CG-49, the other non-VLS ship, is stationed in Yokosuka and participates in regular carrier battle group operations.

The decision to use four of the non-VLS ships for less-demanding missions has several implications for their O&S cost. First, their lower operating speed profiles means lower unit costs for fuel. Second, their modification costs are less because the Navy has chosen to spend less money on modifications. There has been no decision to backfit VLS on these ships or to give them many of the major upgrades that have been applied to the VLS ships. (The non-VLS ships are equipped with the high-technology SPY-1 radar, part of the Aegis combat system, but have Mk-26 surface-to-air missile launchers instead of the VLS.) Third, since many upgrades signify an increase in complexity, denying them to the non-VLS ships may have led to a reduction in their repair cost as well.

Figure III-9 shows average depot maintenance cost per ship as a function of age for the VLS ships only. These costs also show up-and-down behavior.

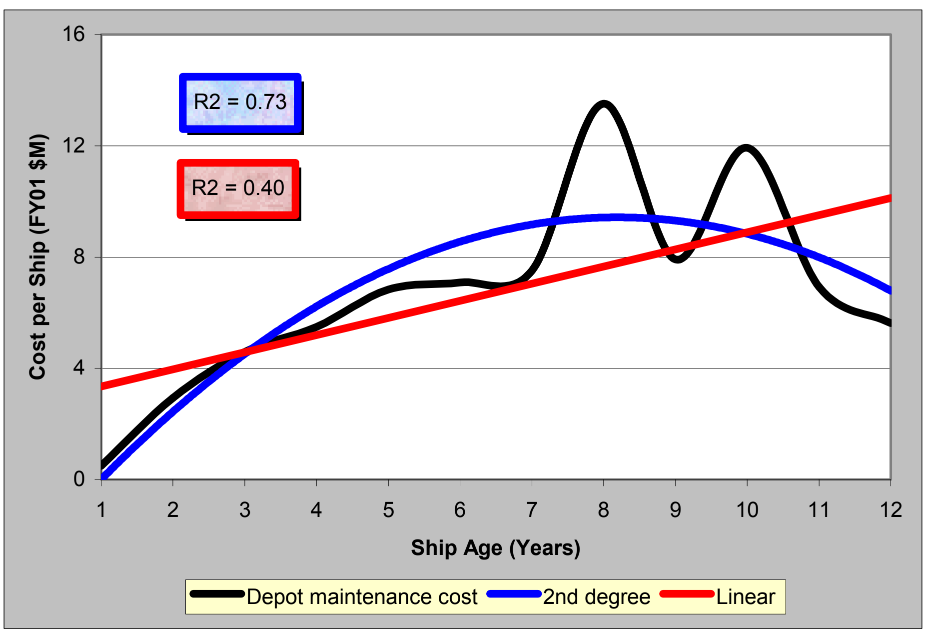

Figure III-9. Average Depot Maintenance Cost per Ship: VLS Ships Only

As with total O&S cost, the up-and-down behavior of depot maintenance makes future prediction of O&S cost uncertain. Although the linear equation shows an upward trend, it does not fit nearly as well as the second-degree equation, which shows no such trend. As before, we found no consistent increase of cost with age.

Figure III-10 shows the repair and modernization components of depot maintenance cost. They are roughly equal contributors to total maintenance cost, and are explored further in the following subsections.

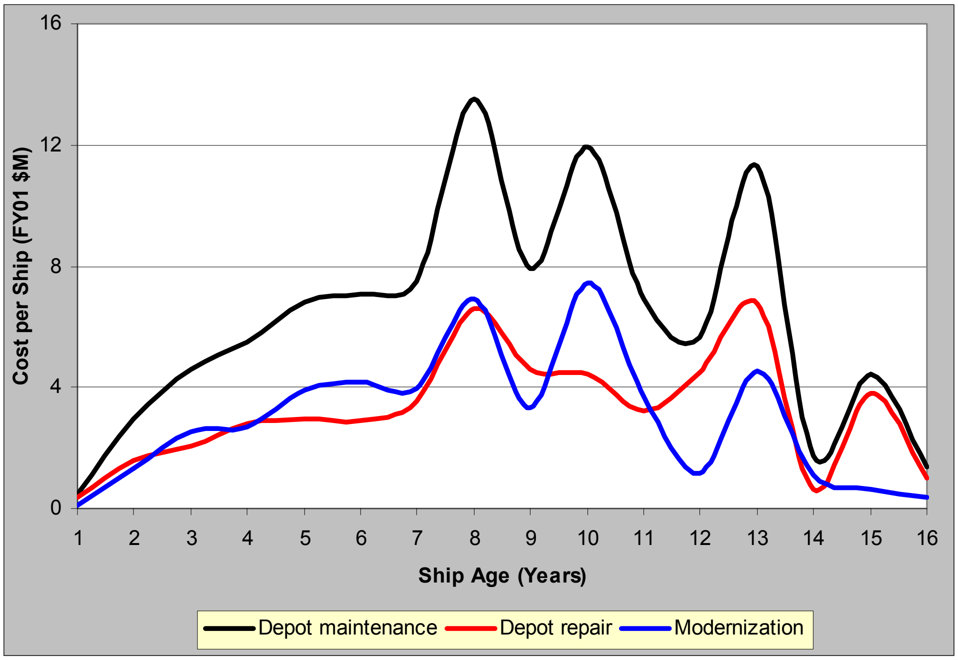

Figure III-10. Average Depot Repair and Modernization Costs per Ship

a. Repair

Figure III-11 shows that repair costs fluctuate due to the maintenance cycle with peaks at 8, 13, and 15 years. The fact that the last peak is lower than the others is possibly due to less care of the non-VLS ships because of their smaller complexity and use in less-strenuous missions.

The maintenance cost is not affected by the presence of the Smart Ship modifications to the CG-48, and more recently the CG-47. These modifications introduce automated features into the ships' bridge and steam rooms to reduce the size of the crew. Although the changes to the CG-48 were made during the years of our data, shipboard assignments were revised during those years to employ the personnel no longer needed for the bridge and engine room to other shipboard tasks. Our data thus do not reflect savings in total ship manning.

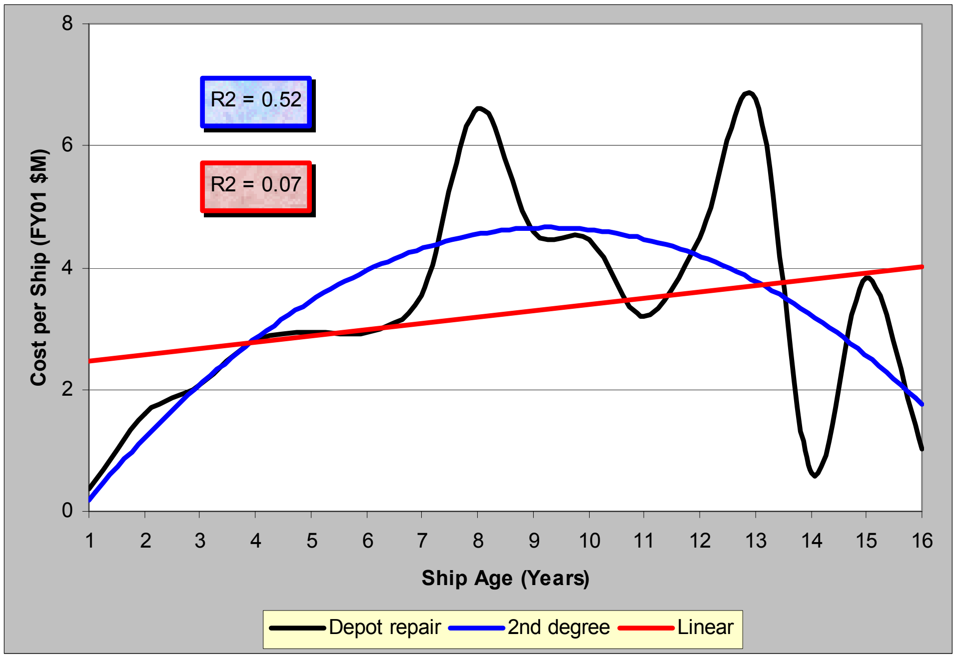

Figure III-11. Average Depot-level Repair Cost per Ship

The VLS ships (Figure III-12) do show an upward trend with age, but it is far from consistent—and the second-degree equation fits much better.

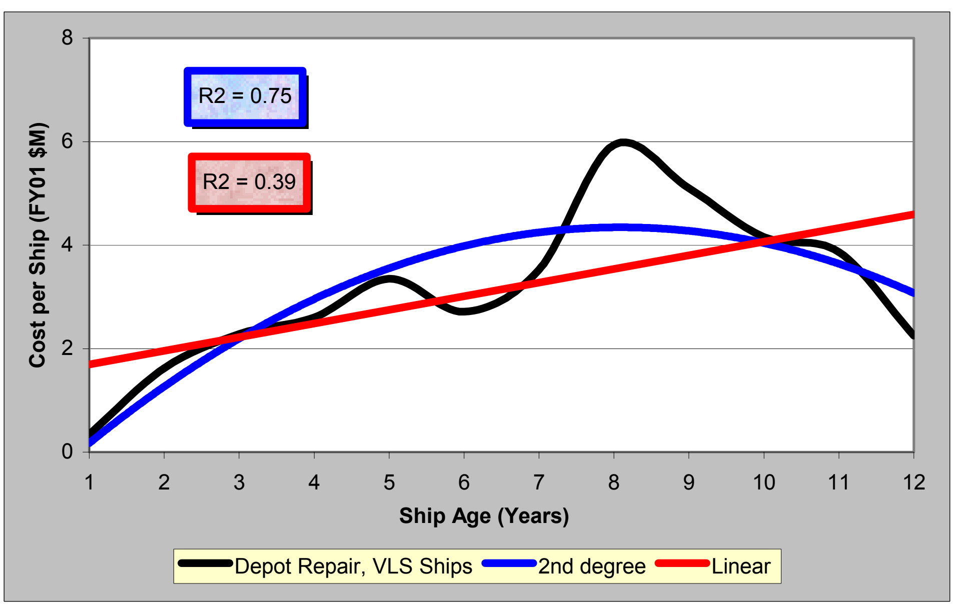

Figure III-12. Average Depot-level Repair Cost per Ship: VLS Ships Only

b. Modernization

Figure III-13 shows that modernization costs fluctuate as do repair costs, with peaks at 8, 10, and 13 years. The peaks occur on a somewhat similar schedule as the pattern of repair cost. Although the two operations have different drivers—modernization responds to the enemy threat and defenses, while repair responds to equipment failure and holding the line on future maintenance cost—the two operations are coupled because both are performed during major availabilities.

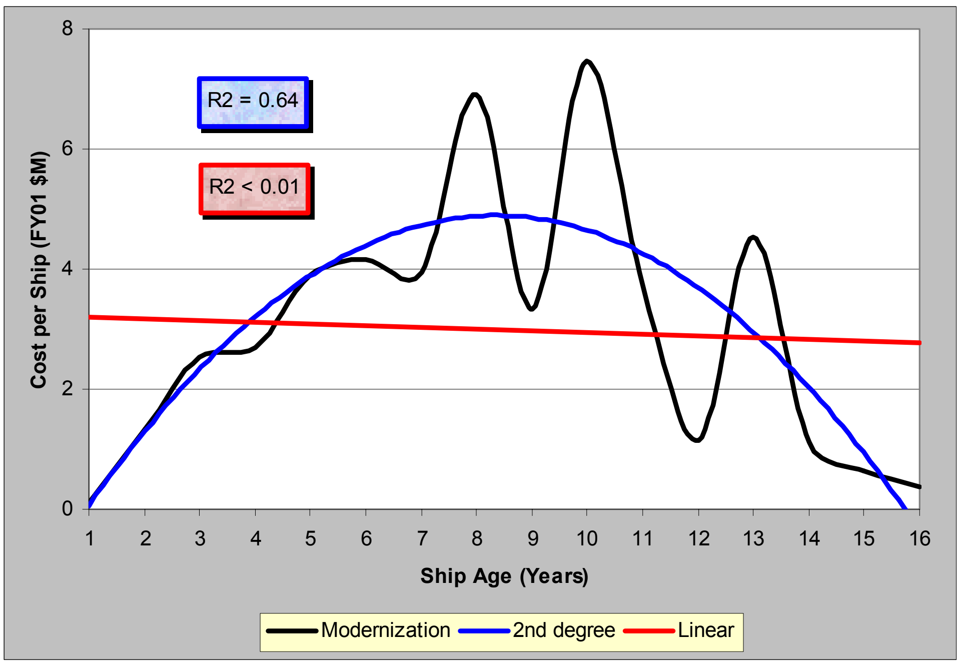

Figure III-13. Average Modernization Cost per Ship

As with repair, the smaller peak of modernization cost at the older ages is probably due, at least in part, to the less-demanding missions of the five Block 1 (non-VLS) cruisers (CG-47 through CG-51). In fact, the Navy has chosen, as a matter of policy, to spend less money on modifying these ships with major upgrades. There has been no similar decision to spend less money on repairs.

Modernization of the VLS ships (Figure III-14) shows a similar pattern to repair cost—a linear upward trend, but still significant peaking behavior with age. Spending for modernization has decreased despite some continual funding of CG-47 class upgrades.

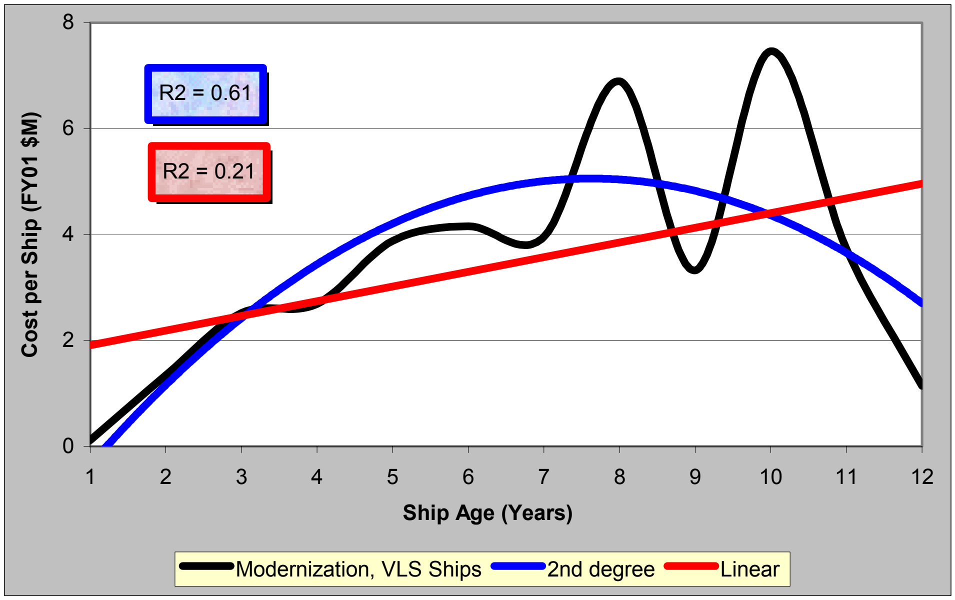

Figure III-14. Average Modernization Cost per Ship: VLS Ships Only

The peaking behavior we see in the spending for repair and modernization as a function of age appears to be contrary to the fact that ships eventually need more support as they get older. However, we show some analysis in Chapter VII that suggests that the lack of a strong upward trend is *not* due to the fact that the CG-47s are still too young to show the eventual increase.

Rear Admiral Michael Mullen presents an interesting explanation in a recent edition of *Inside the Pentagon*. He said, "Historically what happens is we decommission ships based on their combat systems' obsolescence, not on their hull obsolescence. Statistically, if you look back at cruisers you will see that for those that we didn't modernize, we decommissioned them at about 14 to 17 years."[3]

The Navy has no plans to decommission these ships, and in fact recently set aside $2.1 billion in the FYDP (Future Years Defense Plan) for its major cruiser conversion plan for the CG-47s.[4] But the Navy might have been cutting back on CG-47 repair and modernization funding in prior years as a holding position, either in anticipation of receiving substantial funds for the conversion program, or to avoid spending money in the

3 "Without Upgrades, Navy Fears Early Retirement of Aegis Cruisers," in *Inside the Pentagon*, Vol. 16, No. 22, June 1, 2000, p. 12.

4 "Rempt Places Cruiser Conversion Program on Top of Priority List," in *Inside the Navy*, Vol. 14, No. 2, January 15, 2001. The plan would involve giving the ships the capability for Theater Ballistic Missile Defense, the Air Defense Commander system, and the Land Attack mission.

event it would have to decommission the ships. (Note that the title of the article referred to in footnote 3 suggests that the Navy was considering decommissioning as an option.)

C. COMPARISON OF FINDINGS WITH RECENT ANALYSIS

A recent study by the Naval Center for Cost Analysis (NCCA) found similar results to our own regarding the peaking behavior of cost versus age—not only for depot-level maintenance cost, but also for their calculation of organizational-level maintenance costs, which we have not analyzed.[5] NCCA calculated the organizational-level (O-level) maintenance costs as follows:

$$\text{O-level maintenance cost} = (\text{O-level maintenance man-hours} \times \text{E5 wage rate}) + \text{cost of repair parts and repairables}$$

[5] Colleen Adamson and Deanna Ohwevwo, "Impact of Age on Ship Maintenance Cost," Naval Center for Cost Analysis briefing, 12 July 2000, and telephone conversations between Daniel Levine and Colleen Adamson.

IV. O&S COST TRENDS OVER TIME

A. UNIT-LEVEL COSTS

We now shift focus to the behavior of maintenance costs and maintenance time over calendar time. The high costs upon introduction of the CG-47 class (Figure IV-1) may be due to some infant mortality associated with ship class, instead of the normal association with maintenance cost of individual hulls. The high initial costs would be higher yet if we had included the post-shakedown availability costs, which are funded out of procurement accounts, not O&S. The surge in FY 1991 is almost certainly due to the Persian Gulf War.

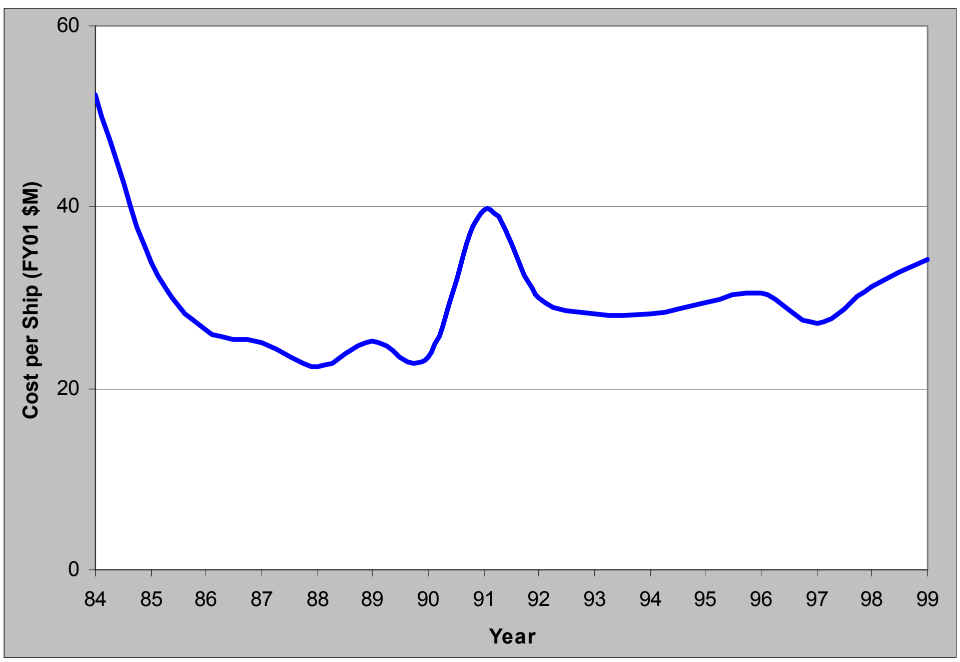

Figure IV-1. Average O&S Cost per Ship

Average unit O&S cost and depot maintenance (Figure IV-2) are the major components of total O&S cost. Intermediate maintenance and indirect costs are negligible percentages of total O&S and are not discussed further. (The VAMOSC data for intermediate maintenance use input from the Navy 3-M reporting system that includes the personnel costs of all Navy and civilian workers, including retirement allowances for the Navy people.)

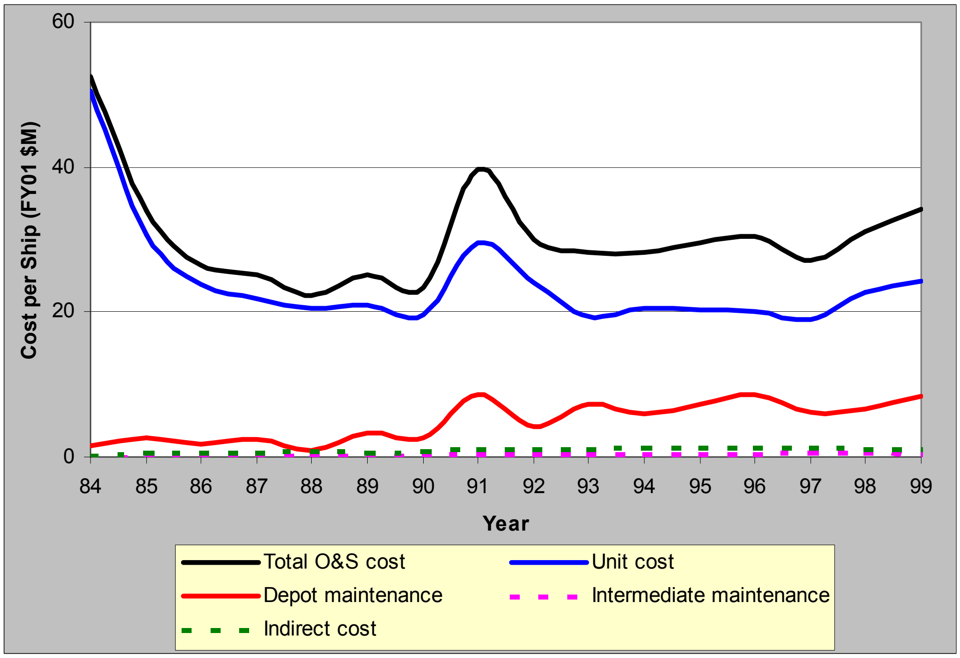

Figure IV-2. Components of Average O&S Costs per Ship

Personnel, fuel underway, and ammunition are the major contributors of average unit O&S cost (Figure IV-3). Costs of repair parts and repairables are relatively small and fairly constant.

Personnel cost rose by almost 60% during 1984 to 1999 (Figure IV-4). Approximately half of the increase (29%) was due to an accounting change to "composite" pay rates in FY 1998. These rates include a share of retirement pay, Permanent Change of Station, and some other smaller items that were not included in the previous rates (which were primarily base pay and allowances plus incentive, specialty, and combat pay). The effect of the accounting change is significant because retirement pay is substantial.

The following two other changes help to explain the remaining 30% increase in personnel cost: (1) an increase of in-grade pay rates apart from the accounting change, and (2) a substantial rise in the seniority mix of Navy enlisted personnel during the period. In the second case, for example, the percentage of first termers fell from approximately 50% to 40%, which means an increase of more senior personnel from 50% to 60%, or 20 percentage points. Our data show no upward trend in crew size.

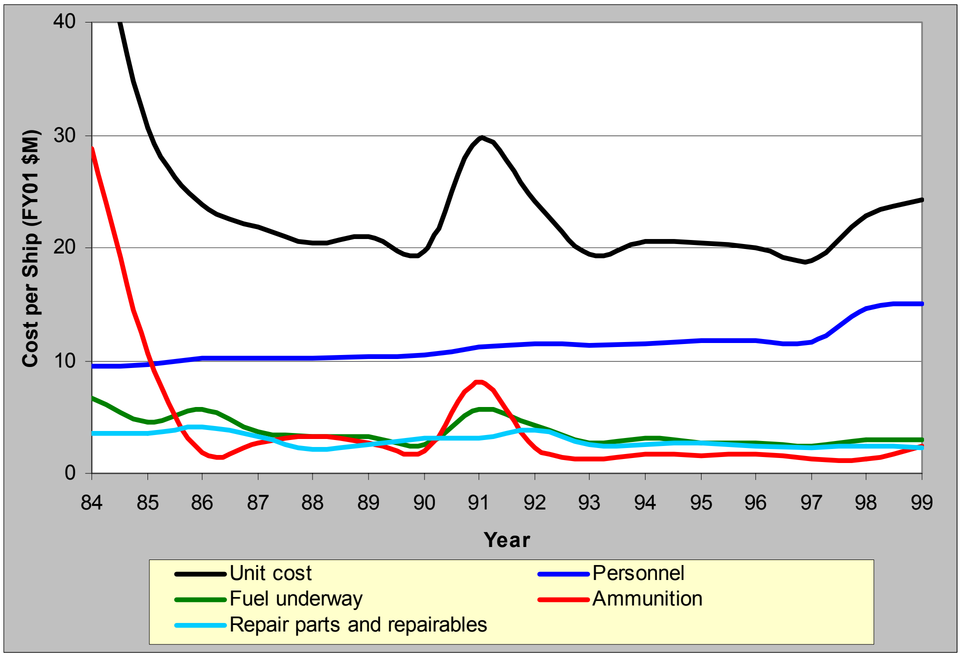

Figure IV-3. Components of Average Unit O&S Cost per Ship

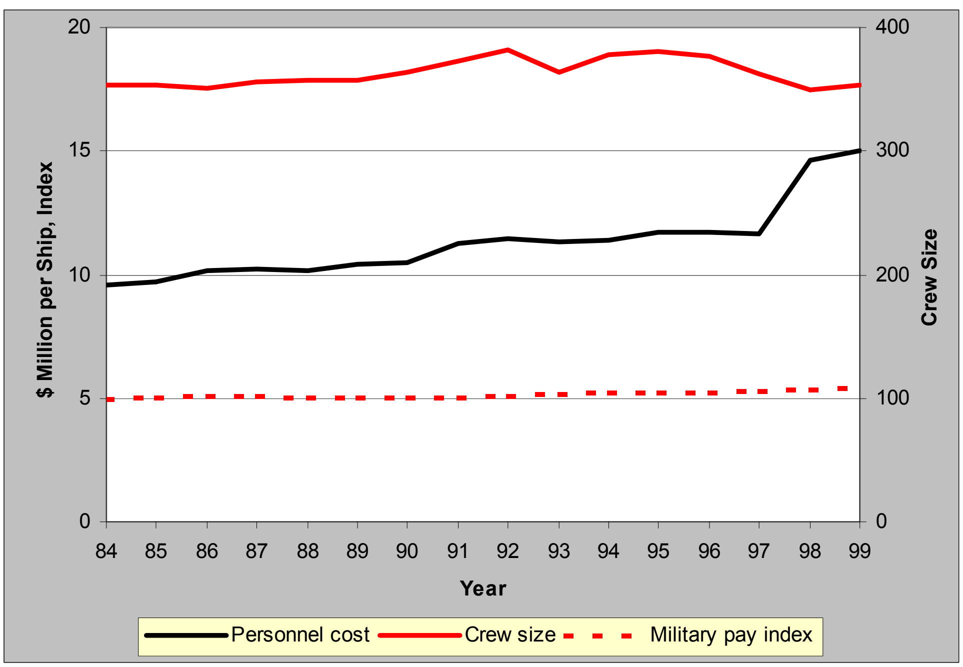

Figure IV-4. Average Personnel Cost per Ship

As we mentioned previously, the new Smart Ship program had no appreciable effect on personnel costs. The program had been applied to only the CG-48 during the period of our analysis, and although it was intended to reduce ship manning by 2 officers and 44 enlisted personnel through automated bridge and engine room, the personnel changes had not yet been made.

Fuel underway cost (Figure IV-5) fell significantly during the period, due, at least in part, to parallel down-trends in a fuel price index and steaming hours underway. (The choice of scale we've used to represent the latter variable masks the approximately 50% reduction.) There was no significant change in barrels per steaming hour underway.

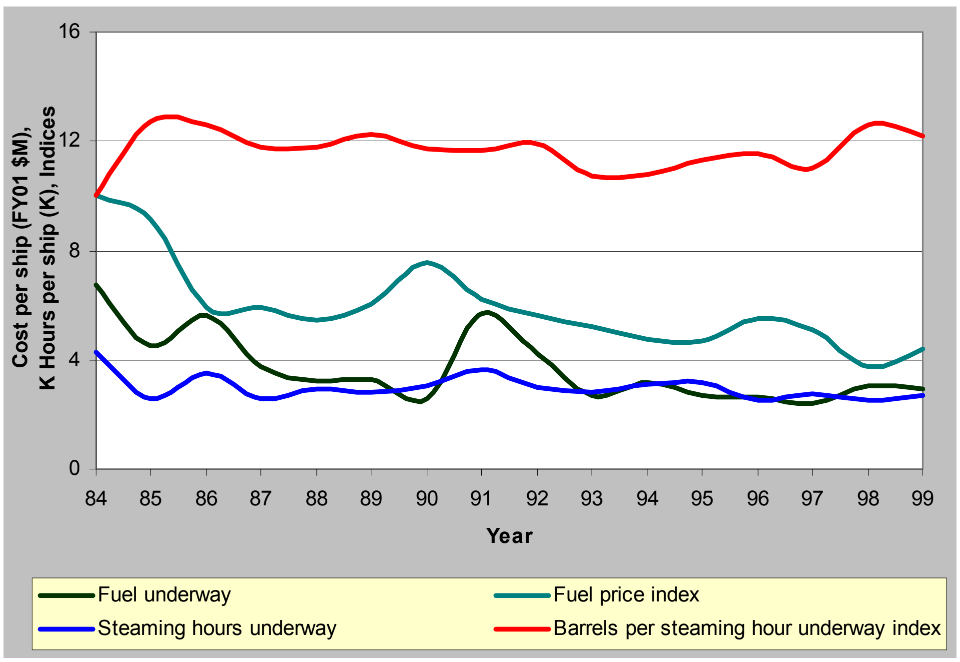

Figure IV-5. Average Fuel Underway Cost per Ship

The fuel price index was calculated from energy prices per gallon contained in the Department of Energy's *Annual Energy Review for 1999*.[1] We mistakenly used prices for jet fuel rather than diesel, despite the fact that the Navy powers the CG-47's LM-2500 gas turbines much more with Diesel Fuel Marine (NATO designation F-76) than JP-5. However, the correlation between the two is 0.973, and we are focusing only on changes.

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1 Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, *Annual Energy Review for 1999*, July 2000, Table 5.20, p. 159.

(Another choice would have been using re-seller rather than end-user prices, but these prices are even closer, with higher correlation coefficients of over 0.99.)

To make the fuel prices consistent with the other costs in this study, we deflated them by the Consumer Price Index (CPI) obtained from the St. Louis Federal Reserve System bank.

The age analysis in the previous chapter revealed a peak in ammunition use of each ship after its commissioning. In Figure IV-6, we see a peak upon introduction of the CG-47 class in FY 1984 due to the same factors: personnel training and weapon system testing. The FY 1991 peak is certainly due to replacement ammunition following the Persian Gulf War.

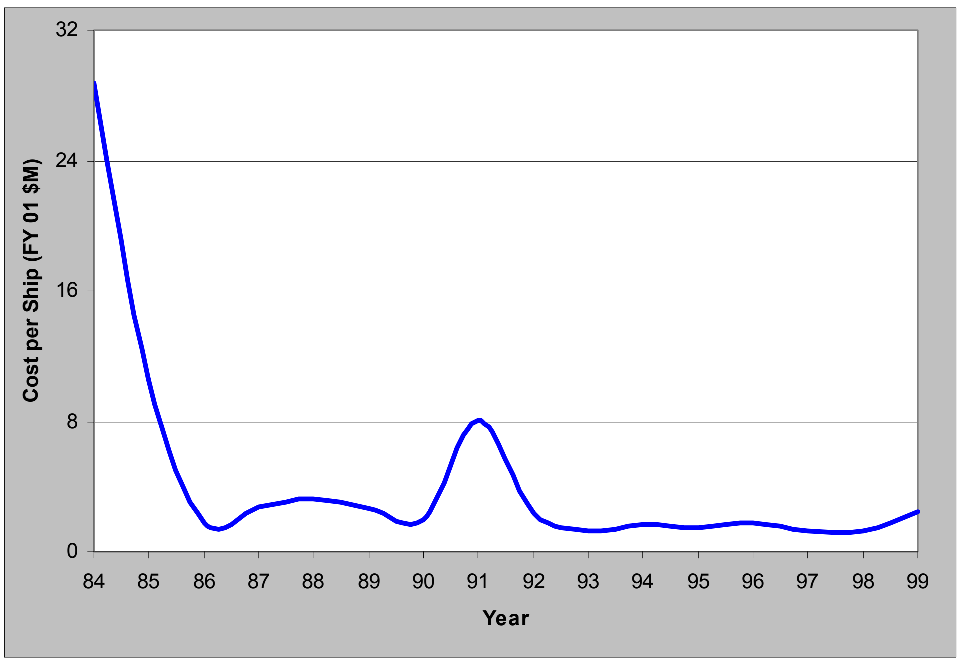

Figure IV-6. Average Ammunition Cost per Ship

B. DEPOT-LEVEL MAINTENANCE COSTS

We now turn to the question of whether recent changes in Navy maintenance policy have had the expected effects of lower maintenance costs and time, and a shift from availabilities scheduled by the Chief of Naval Operation (CNO) to those secheduled by the Type Commander (TYCOM).

1. Recent Changes in Maintenance Policy

The Navy has made three types of policy changes in the last 20 years to increase the efficiency of its maintenance actions:[2]

- Shifts from lumpy to smooth maintenance schedules,
- Shifts from time-based to condition-based maintenance, and
- Shifts from a single comprehensive assessment to more frequent and focused assessments for identifying and planning workloads for upcoming maintenance availabilities.

The shift from lumpy to smooth maintenance schedules is described as from “consolidated” to “phased,” “distributed,” and “continuous” maintenance in the language of Navy directives. The intention is to shift some of its depot-level maintenance from the long and infrequent CNO availabilities—Regular Overhauls (ROHs) and Selected Restricted Availabilities—to the shorter but more frequent TYCOM availabilities—the old Restricted Availabilities (RAVs) and Technical Availabilities (TAVs). CNO availabilities are still required for major hull, mechanical, and electrical repairs and modifications, although time for hull repairs has been shortened and hulls are often cleaned by special cleaning devices at the pier. Repair of complex combat and sensor systems (fire control systems, Aegis radar, etc.) are still done in CNO availabilities, but the Navy has re-designed some of its combat systems and system upgrades so they can be done in the shorter RAV and TAV availabilities, in some cases, over a span of several availabilities.

The shift from the time-based to the condition-based maintenance philosophy was instituted in the early 1990s. Condition-basing means “fix it if it looks like it needs it,” not “fix it every 4 years, whether it needs it or not.” (Time-based schedules can be in calendar or operating time.) Condition-based scheduling is most appropriate for equipment that meet the following criteria:

- Measures of material condition can be easily observed. Examples are vibration, noise levels, and quality of lubricating oil.

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[2] This material was obtained from many discussions with a variety of sources, including Mr. Robert Lindner (Plans and Policy Manager at Commander Naval Surface Force Atlantic in Norfolk), CAPT John Woodburn (former Deputy Director of N-43, Supportability, Maintenance and Modernization in the Office of Chief of Naval Operations), PMS-400 (the Aegis Program Manager), and T. M. Hopkins, RADM USN (Ret.), and Edward McGinley, RADM USN (Ret.), both former Fleet maintenance officers now at IDA.

- The equipment is not mission-critical, so equipment problems resulting from failures of condition-basing do not lead to lost operating time.
- Failures are not reliably predictable in time, so pre-set repair times are not efficient.
- Condition-based testing is not costly in money and time.

Surface Force, Atlantic Fleet (SURFLANT) officers told us that the Navy now uses condition-basing for 95% to 97% of the maintenance on its surface ships.

The Navy hopes to further reduce maintenance costs by adopting more frequent and more narrowly focused assessment visits, and by making sure that plans and material are in hand before the start of availabilities. The new procedure is to perform four assessments per cycle, each dedicated to a different area of ship maintenance to avoid interference. In addition, the POT&I and SEMAT assessments have been expanded as part of the new continuous maintenance policy. Inspectors perform more systematic checks of indicators of material condition that can be easily measured, such as vibration, quality of lubricating oil, and bearing temperatures of rotating machinery.

The hope is that the narrow focus will avoid the problems of a single inspection time and interference between different areas of maintenance.

2. Analysis

Before beginning the discussion of our analysis of maintenance data, we should make a few points about the data itself. First, because different availabilities can be performed concurrently, much data manipulation was needed to estimate how much time ships spend in maintenance, when they are not available for missions. For example, maintenance officers have told us that tasks that are contracted out during an ROH can be reported as RAVs or TAVs, so adding up the times in all availabilities can greatly overstate the total time the ship is standing down for maintenance during the year. Although overlaps may reflect different maintenance actions that occur concurrently, we eliminated the overlaps since we were focusing on time in maintenance rather than total workload.

There were no similar problems with the VAMOSC cost data, however. The maintenance costs for scheduled (CNO) availabilities and unscheduled (TYCOM) availabilities were costs for repair only, and the costs for Fleet Modernization Program were for modifications only. We were therefore able to determine separate cost trends for both repair and modernization.

It was difficult, however, to separate out the duration of the modification periods under the Fleet Modernization Program. The problem was that most modifications (certainly all major alterations) are carried out during maintenance availabilities, and VAMOSC describes them by the start and completion dates of the entire availability. For example, the start and completion times for a modification carried out during an ROH may be reported twice—once for the modification alone, and once for the entire ROH.

Another problem was that private shipyards do not provide visibility into their availability costs. They report only total cost of availabilities, not the data for labor cost, material cost, overhead cost, and labor man-days.

Average depot maintenance costs per ship did, in fact, rise during the period (Figure IV-7). The behavior holds for both repair and modernization, which share roughly equally in depot-level maintenance cost. (Although maintenance is sometimes used synonymously with repair, we are using it for the sum of repair and modernization.) We do not understand why the up trend started in FY 1989, since there was little expectation of a Persian Gulf War at that time.

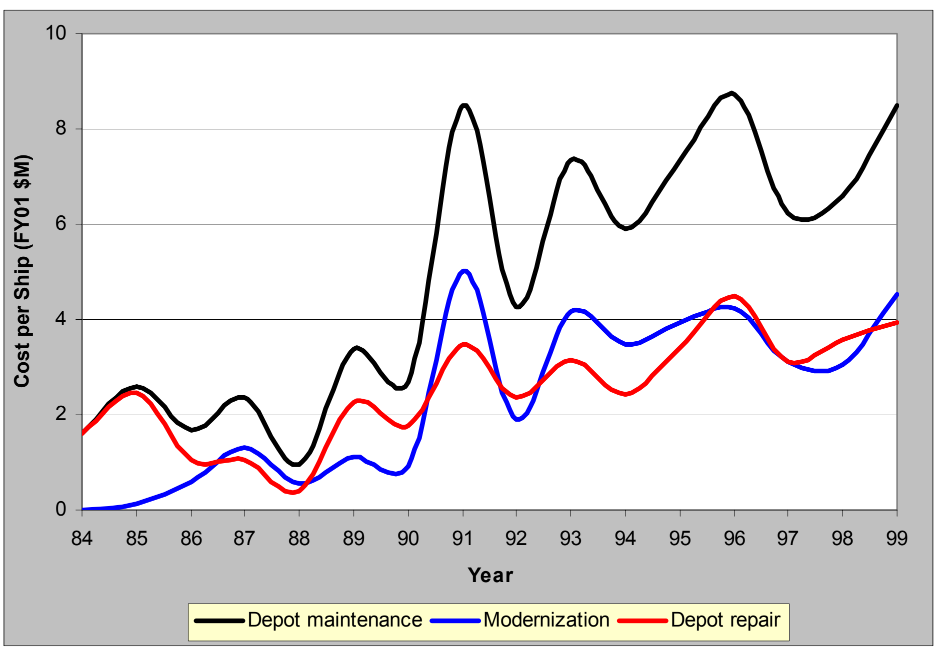

Figure IV-7. Average Depot-level Maintenance Cost per Ship

The high levels occurring in FY 1991 and beyond were direct results of the Persian Gulf War. Approximately 170 Navy ships and submarines participated in Desert Shield/Desert Storm at some point between the onset of Desert Shield on August 22, 1990, and the formal cease-fire of the war on April 11, 1991. As an indication of scale, the involvement included 41% of the CG-47s (11 out of 27) and 62% of the CVs/CVNs (8 out of 13 active on September 30, 1990; there were 15 one year later).[3]

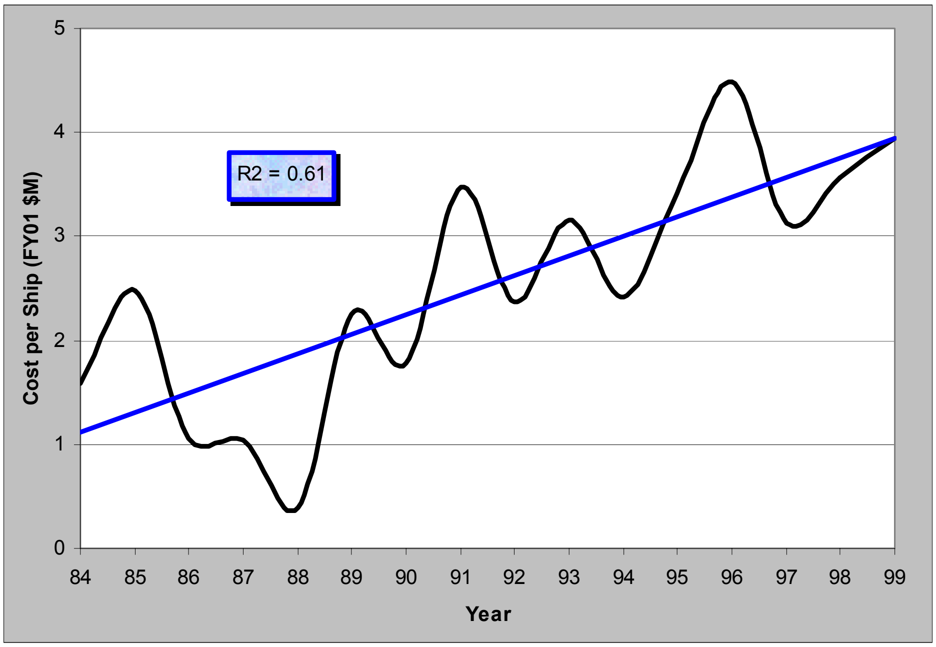

Figure IV-8. Average Depot Repair Cost per Ship

Despite the lack of significant battle damage and the short duration of the war, the war imposed a heavy maintenance cost on the Navy after the war for two reasons: many ships had been subjected to high operating tempos, and many had missed their scheduled maintenance availabilities for both repair and modernization. (Battle damage was relatively minor, limited to costly repairs of the CG-59, which struck a mine, and some repairs of damage to the LPH-10 (USS *Tripoli*), an amphibious assault ship.)

Regular maintenance could not be done in the theater because of the press of operations and because of the restriction against use of foreign repair facilities except for emergency repairs. The large amount of deferred maintenance thus led to a huge maintenance backlog when all these ships came home at the cessation of hostilities in

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3 The ships assigned to the Persian Gulf War are from "The United States Navy in 'Desert Shield' Desert Storm," Department of the Navy, Office of the Chief of Naval Operations, 15 May 1991. The dates and carrier force levels are from the Naval Historical Center's web site at http://www.history.navy.mil/branches/nhcorg9.htm, January 24, 2002 (accessed March 6, 2002).

April 1991. The result was the high repair costs shown in Figure IV-8 for the years after the war.

Another possible contributing factor to the growth in repair costs might be the upward trend in complexity of modifications following the war. (We will shortly see that modernization costs rose sharply during the period.) The CG-47 fleet in later years contained both young and old ships, and since we found that repair costs fell for the older ships, the increase in cost for the later years means that the newer ships were becoming much more costly.

Although the upward trend in repair costs seems clearly related to the Persian Gulf War, the marked fluctuations are difficult to understand. Since construction of the CG-47s was spread over much of the period (commissioning occurred during FYs 1983 to 1994), maintenance cycles, which inherently depend on age, would not likely show up as a function of calendar time.

As we mentioned previously, an upward trend in modification costs is another result of the maintenance backlog due to the Persian Gulf War (Figure IV-9), but it seems to be the result of a step-up in two relatively stable populations during 1984 to 1990 and 1991 to 1999.

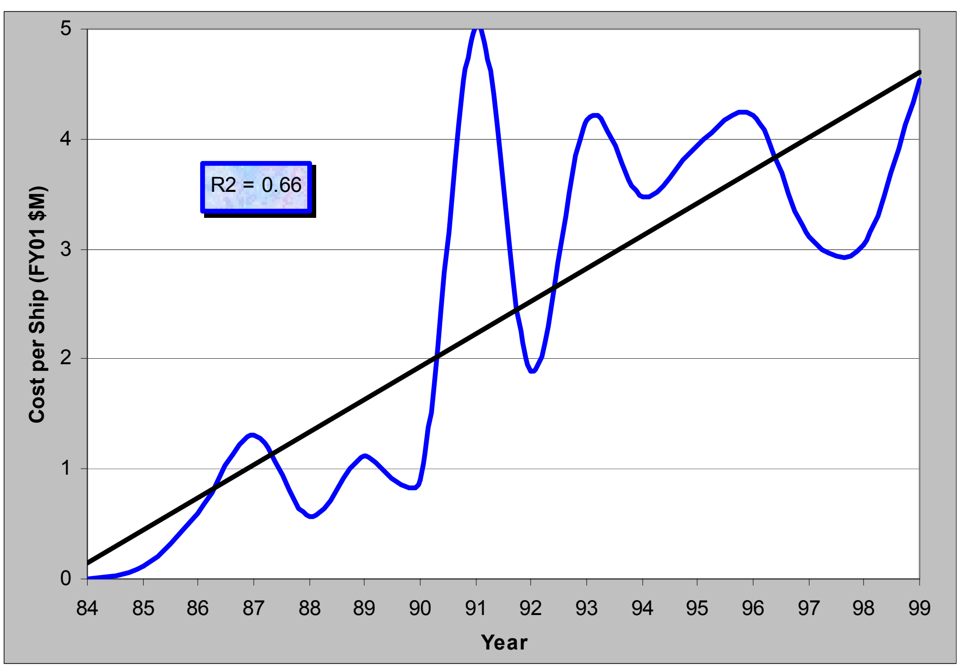

Figure IV-9. Average Modernization Cost per Ship

We found mixed results regarding our expectation that the recent changes in maintenance policy would lower maintenance costs and shift them from CNO to TYCOM availabilities (Figure IV-10). The sharp upward trend in total repair cost (CNO plus TYCOM) was unexpected, but TYCOM availabilities have been handling a larger percentage of the total, as expected.

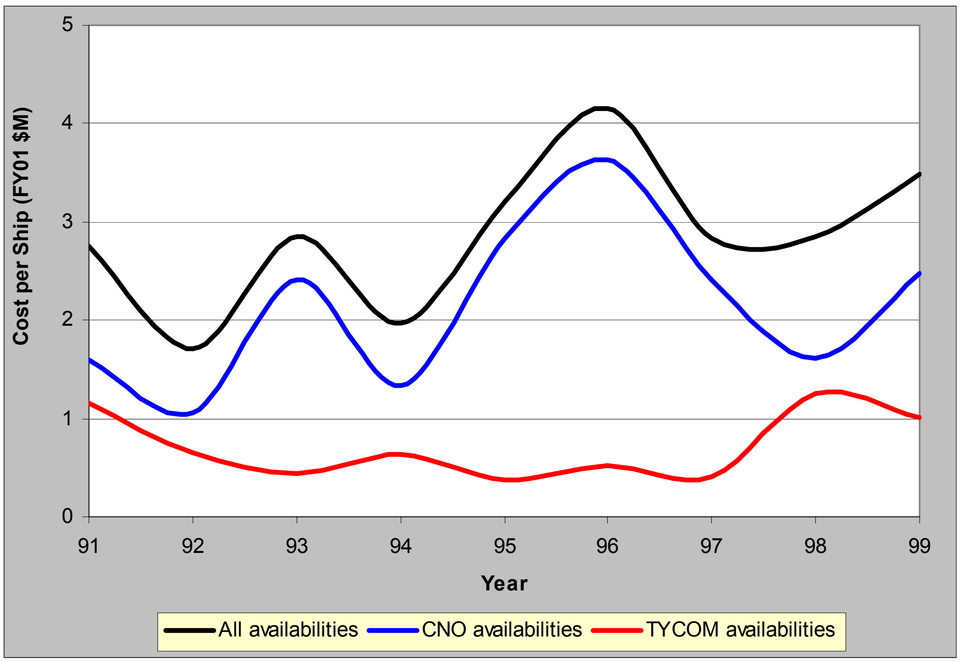

Figure IV-10. Average Repair Cost per Ship

Let's briefly turn our attention from maintenance cost to time (Figure IV-11). Because the figures for the first and last years are extreme and thus suspect, we focus on the trends between the dotted green lines. The results for maintenance time are mixed, as they were for maintenance cost. The upward trend in maintenance time (average per ship per year) is contrary to what we would expect from the recent changes in maintenance policy, but later years saw a much larger percentage of total time spent in TYCOM availabilities. (The total maintenance time data are not separated into repair and modernization.)

The observation of 7 months per year for depot-level maintenance seems extremely high, but most of the time is for TYCOM availabilities, and many of these are TAVs. At least some of these can be conducted while ships are alongside piers or at sea, without pulling ships out of normal service.

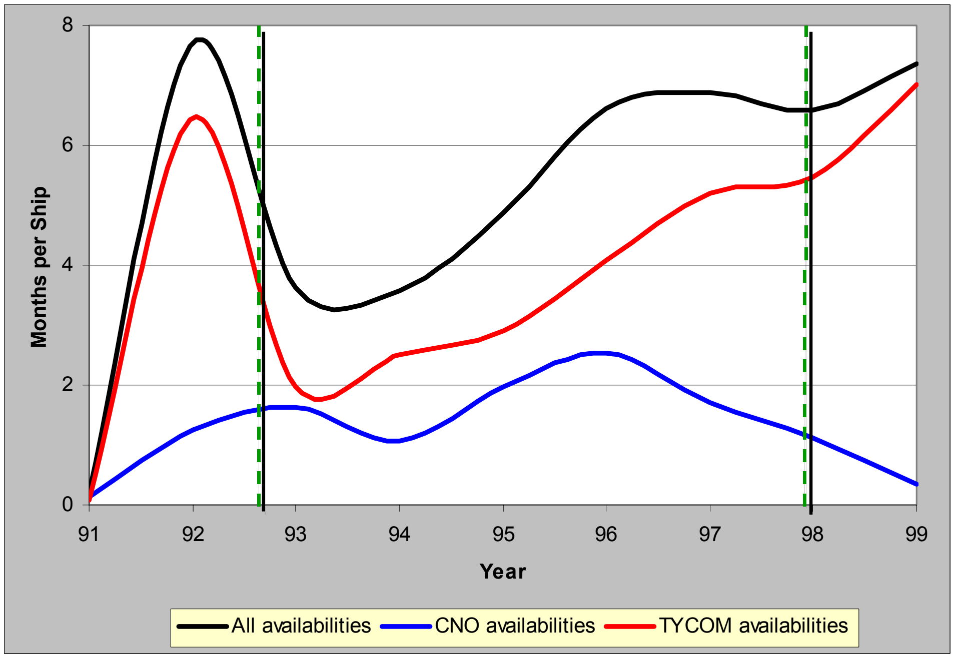

Figure IV-11. Average Depot-level Maintenance Time per Ship

The data also show fairly constant costs per availability month for both CNO and TYCOM availabilities (Figure IV-12). This suggests that there has not been a large change over time in the average man-hours of the work being done in these two types of availability.

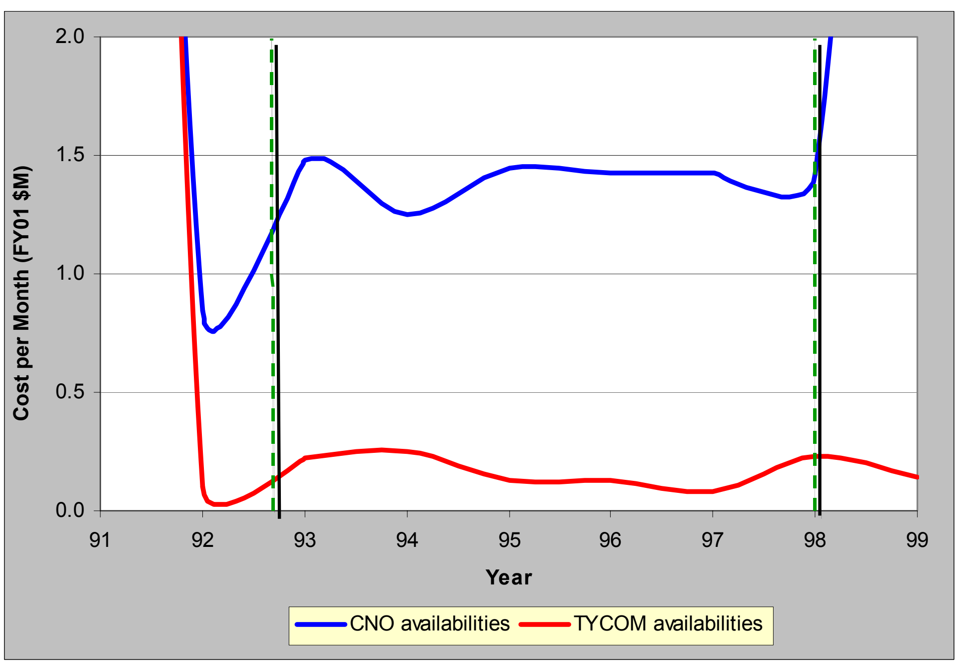

Figure IV-12. Repair Cost per Total Availability Month

C. SUMMARY

During the most recent years from FY 1993 through FY 1998, maintenance cost and time in CNO and TYCOM availabilities have both increased, with a shift toward TYCOM availabilities. The cost per unit of time has remained fairly constant.

We offer some important caveats in interpreting these results. First, the Fleet people we talked with say that the policy changes are far from being fully implemented. The shift from CNO to TYCOM availabilities may be slowed because the ship commanding officers who take their ships into availabilities and the maintenance personnel who schedule the service still have incentives, despite the CNO directives, to fix as many things as possible when they have the opportunity.

Also, the fact that maintenance costs are rising does not necessarily mean that the maintenance policies are *not* effective. It is possible that the costs are rising for other reasons and would have risen even more in the absence of the policies. Possible reasons for the rise in maintenance costs include increases in ship age, complexity, and shipyard wage rates and overhead costs.

Insofar as the above factors lead to inefficiency, they also help to explain why maintenance *times* have been rising.

As a side matter, one might expect that the Navy's new policy of moving to more TYCOM availabilities might, until experience is gained, lead to an over-reduction in insurance repairs with a consequent increase in emergent (unplanned) spending. SURFLANT figures suggest, however, that this has not occurred—its emergent spending has not risen significantly. Moreover, even if emergent spending were, in fact, rising, it would not necessarily indicate that implementation of the new maintenance policies was at fault. The problem could be due to reduced maintenance spending brought about by the increasing tightness of the Navy budget, or a move, as some expect, to diseconomies of scale resulting from the current contraction in shipbuilding. To separate out these effects, we held the Navy budget constant in our regression analysis (discussed in the following chapter).

V. REGRESSION ANALYSIS OF O&S COST VERSUS AGE AND OTHER DRIVERS

The graphs in Chapters III and IV give a quick intuitive picture of how CG-47 O&S costs depend on age and time separately. The approach suffers, however, from the fact that O&S costs depend on variables other than age and time. In the graphs in Chapter III, for example, the age variable would be standing in for all other drivers, so the graphs do not isolate the effect of age alone.

We therefore performed a regression analysis to see if our results were robust—that we would obtain similar results by considering the joint effect of age, year, and several other drivers. By including all these variables, we hoped to more clearly identify the separate effect of age, holding all the other drivers constant.

We analyzed the CG-47 class alone and also along with the following other major surface combatants: the DDG-51 destroyers, which are still being built, and the considerably older DD-963 destroyers and FFG-7 frigates. The purpose of the latter regression was to see if the reason we failed to find a strong dependence of O&S cost on age was the relative youth of the CG-47s.

The dependent variable is the aggregate measure we already considered, average annual O&S cost per ship in millions of FY 2001 dollars. We chose the following independent variables (cost drivers):

- Year (1984–1999),
- Ship age, in both linear and quadratic (squared) form,
- Ship manning level,
- Ship annual steaming hours (total, underway, and not underway), a measure of OPTEMPO,
- Dummy variables for the sophistication of a ship's sensors, weapons, and propulsion,
  - Aegis (1 for all CG-47s and DDG-51s, 0 otherwise),
  - VLS (1 for the last 22 CG-47s and all DDG-51s and DD-963s, 0 otherwise),

– LM-2500 gas turbines for propulsion (2 for the FFG-7s, 4 for all others),

- Measures of total Fleet budget and assets,
  – Total Navy budget, and
  – Total Fleet capital value.

We included the total Navy budget since spending on maintenance depends on how much money is available, not just intrinsic needs for repair. The Fleet capital value works opposite to the budget: Holding budget and all else constant, the larger the total Fleet the Navy has to support, the fewer the funds that will be available for maintaining the CG-47s.

We used step-wise regression to identify equations that met the following criteria: (1) high value of R^2 (which indicates the percentage of variability of the dependent variable that is explained by the regression equation as a whole), (2) high t-statistics of the coefficients of the independent variables (which indicate high statistical significance of each), and (3) intuitively correct signs of the coefficients (e.g., positive coefficient of total Navy budget). The step-wise regression routine selected the independent variables to include.

The two regression results (Table V-1) are remarkably similar for the effect of age: highly significant positive coefficients for age and negative coefficients for age squared. Adding dummy variables for ship class as the constant term to the multi-class regression offered no improvement. It would have been interesting to try cross terms between ship class and the coefficients of age and age squared, since CGs, DDs, DDGs, and FFGs all have different average O&S costs (even in FY 2001 dollars), and the effect of age should therefore vary. However, it's difficult to argue with the fact that the coefficients of age and age squared have extremely high statistical significance.

The fact that the coefficients for age and age squared are positive and negative, respectively, implies exactly the same up-and-down behavior found by the previous graphical analysis. That is, cost will initially rise with age but eventually fall to its initial value after approximately 20 to 25 years. For the first regression (for the CG-47s alone), $2.5\,(\text{age}) - 0.12(\text{age}^2)$ has the same value for age 1 as it does for age 19.3. For the second regression (for all four major surface combatants), the expression has the same value for age 1 as it does for age 23.

Note that the annual Navy budget does not appear, but since Fleet capital value has a positive coefficient, it may be acting as an overall demand for O&S funds.

Table V-1. Regression Results

Explanatory Variable	CG-47 Class	CG-47, DDG-51, DD-963, FFG-7
Constant ($M)	0.71	–8.1
Age (Years)	2.5***	2.4***
Age^2	–0.12***	–0.10***
Steaming Hours (K)	–0.80**	–3.8***
VLS (0 or 1)	3.2**	17.2***
Fleet Capital Value ($B)	0.072**	0.10***
R^2	0.07	0.18

Note: Dependent variable is average annual O&S cost per ship (FY01 $M).
** High statistical confidence (5%).
*** Highest statistical confidence (1%).

In summary, our analysis found no consistent upward growth in O&S cost with age.

VI. CASREP ANALYSIS

To supplement our analysis of O&S cost, we analyzed the average number of new Casualty Reports (CASREPs) per ship per year. A ship at sea that sustains an equipment failure may issue a CASREP to obtain rapid supply of critical items, to request visits of experts, and to notify others of loss of operational capability. The captain is required to put in a CASREP if he estimates that the failure cannot be fixed within 48 hours because of lack of parts or repair capability, but may issue a CASREP otherwise.

The two primary questions of interest were whether the incidence of CASREPs increased with age (indicating lower reliability holding everything else constant) and decreased over time with changes in maintenance policy (indicating higher reliability). Other questions are whether trends in CASREP incidence were widespread or localized over a few pieces of equipment and whether incidence varied by hull.

We obtained data from the Navy's Inventory Control Point at Mechanicsburg, Pennsylvania, on over 14,200 new CASREP starts described by severity, hull number, and year. We analyzed the 1,550 CASREPs from 1984 though 1999 that indicated major degradation or loss of capability to perform one or more primary missions. (The CASREP data is in calendar, not fiscal years.) These represent the CASREPS of greatest severity (ratings of C-3 or C-4).

CASREP incidence shows an extremely high increase with age, a four-fold jump from 5 to 20 per ship per year by age 15 (Figure VI-1). The surge to 35 per ship per year at age 16 and the extremely high drop-off at age 17 are probably not significant, since they are for only two and one ship, respectively. Possible explanations for the rise with age are that the older ships are the non-VLS ships, which have not been upgraded, and that equipment problems begin to show up as a ship gets older.

Another possibility is that although maintenance can remove some of a ship's material degradation due to age, it cannot remove all of it. Replacement of a gas turbine effectively reduces the age of this component to zero, but it is prohibitively costly to completely renew distributed systems such as hull structure (e.g., fuel and ballast tanks), fluid piping, and electrical cabling. Age eventually takes a toll. This factor does not explain, however, the seven-fold surge, since problems with distributed systems do not always render ships unable to perform missions.

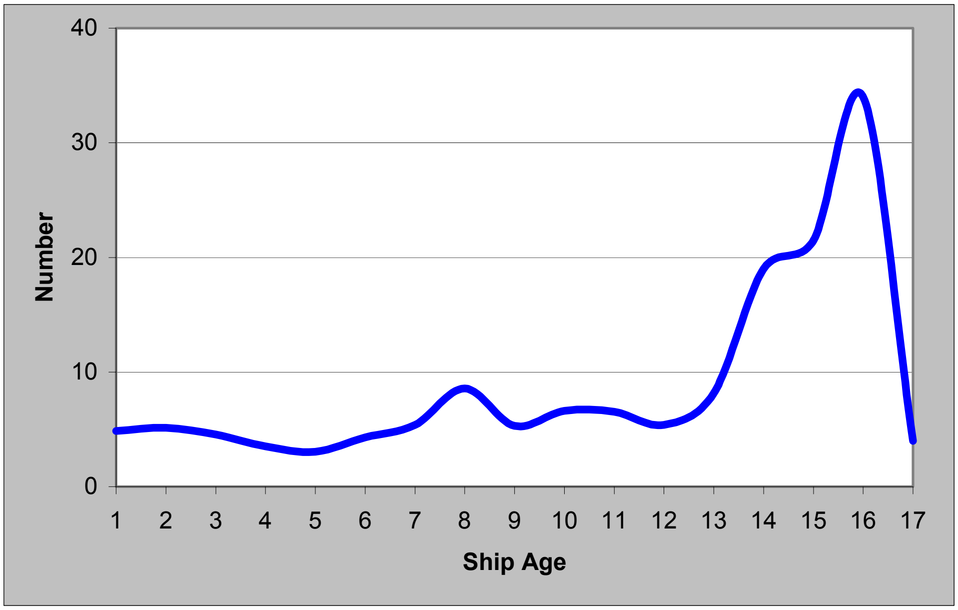

Figure VI-1. C-3/4 CASREP Incidence per Ship by Age

(We handled age and time slightly differently in the O&S and CASREP analyses. Whereas the VAMOSC O&S data starts reporting cost in the first complete fiscal year after commissioning, CASREPs are first reported in the fiscal year of commissioning. The difference had no effect on the results of the analyses.)

CASREP incidence indicates a smaller but still significant rise with time—a doubling from approximately 3 to 6 per ship per year from 1987 to 1990, with little change thereafter (Figure VI-2). We ignored the extremely high values in the initial years. Not all of the few ships that participated in the averages did so for a full year since the CG-48 and CG-49 were both commissioned in mid-year (July).

The strong up trend with age is not inconsistent with the smaller rise over calendar time. The age trend correctly states that CASREP incidence of the CG-47s began to grow significantly at age 14 years. However, these high incidence figures had a diluted effect on the calendar year trend because the first CGs didn't reach 14 years until 1997, by which time all CGs had been commissioned. (Only three CGs reached 14 years of age by the end of our data in 1999, a small part of the total fleet of 27 ships.)

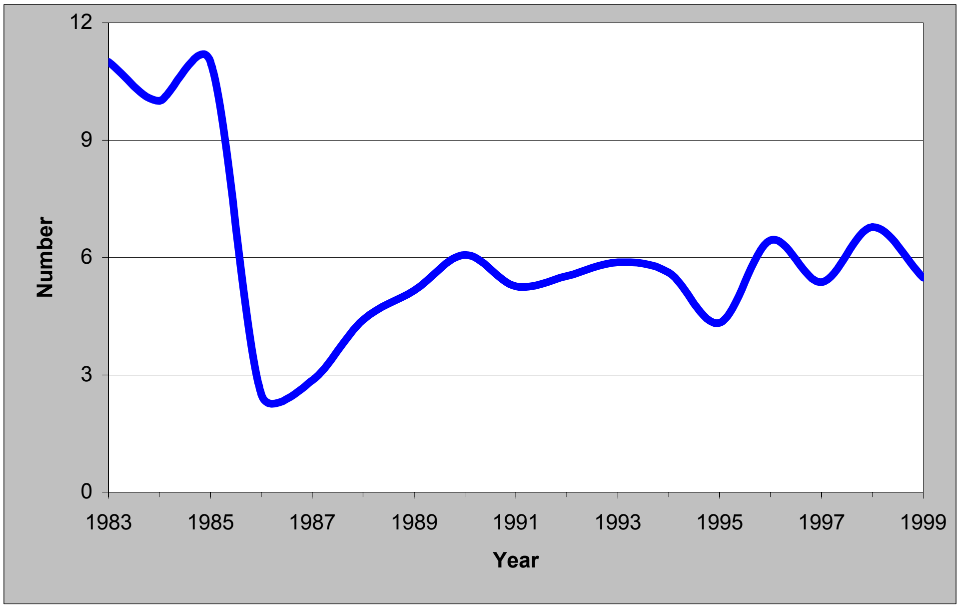

Figure VI-2. C-3/4 CASREP Incidence per Ship by Year

The Navy's reliability problems are clustered around problems with a few types of equipment (Table VI-1). During FY 1983 to FY 1997, only five items of equipment in the gas turbines and generators that produce the ship's electrical power were responsible for fully 22.4% of all C-3/4 CASREPs. And only two items of equipment in the countermeasures set caused a sizable number of problems.

Table VI-1. Equipment Responsible for C-3/4 CASREPs for CG-47 Class Ships, 1983–97

Equipment Identification Code (EIC)	Number	Percent
Electricity Generation		
3510000 turbine assembly, gas SSPU	274	
3560000 control system, generator	23	
3550000 generator, AC	21	
D111000 generator assembly, gas	16	
3500000 generator set, gas turbine	13	
Total	347	22.4%
Countermeasures Set		
AN/SLQ-32(V)3	33	
AN/SLQ-32A(V)3	32	
Total	65	4.2%
All Others	1,139	73.4%
Total	*1,551*	*100.0%*

We previously showed that CASREP incidence increased four-fold as ships became older. Figure VI-3 shows that much of this was caused by growing problems with the eight worst equipments—and particularly with the turbine assembly (Equipment

Identification Code 3510000), which was alone responsible for 274, or almost 18 percent of the total 1,551 CASREPs during the period. The Navy does, however, have a well-organized Top Management Attention–Top Management Issues (TMA-TMI) program to handle these types of problems.

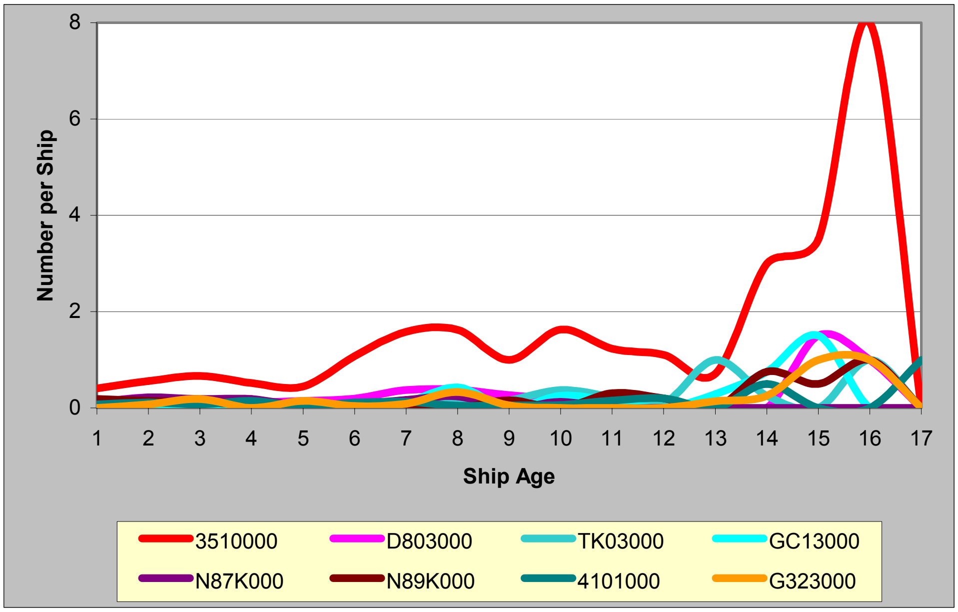

Figure VI-3. C-3/4 CASREP Incidence per Ship by Equipment Type

Because only one ship, the CG-47, is represented at age 17, the fall to zero is not statistically significant.

During the course of this study, Navy maintenance officers frequently pointed out that ships, as well as equipment sometimes cause problems. Our data does, in fact, confirm a significant variation in CASREP incidence across hulls (Figure VI-4). (For security reasons, the index in the figure gives only the relative values of CASREP incidence for individual hulls. A value of 2 means somewhat more than 1, etc.)

Navy maintenance officers also mentioned that CASREP incidence can vary with non-equipment-related features such as the captain's philosophy, the crew's level of maintenance capability, and the battle group's or Fleet's command policy. One captain may under-report CASREP incidence because of a feeling that CASREPs are a black mark—that his job is to do the mission with the resources at hand. Another captain may over-report out of a feeling that if the Navy gives him a job to do, it owes him the resources to do it. Ship maintenance crews certainly vary in their level of training. And high-ranking Fleet operational officers can impose different reporting policies on the ship captains under their command.

The question of interest here is whether these factors are really the cause of the variation with hull number shown in Figure VI-4. The answer is no. The graph shows the average yearly incidence (index) of CASREPs for each hull averaged over the entire period between the hull's commissioning and FY 1997, and the Navy's 2- to 3-year rotation policy ensures that all but the most recently built ships would have had several captains, crews, and Fleet commanders during the period of analysis.

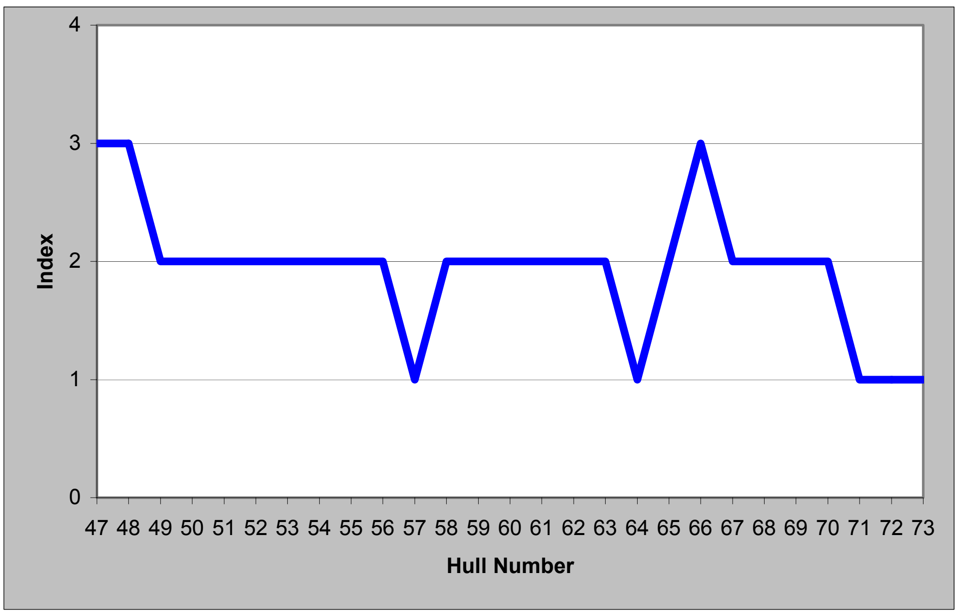

Figure VI-4. Variation of C-3/4 CASREP Incidence (Index) per Hull, 1983–97

We conclude that the variation with hull is real. In fact, a closer look at the experience of individual hulls (not shown) leads to a consistent explanation for the above observations regarding the dependence of incidence on time and age. CASREP incidence was especially high during the early years (1983-84) because the lead ship of the class, the CG-47 hull, had an inordinately high incidence immediately after commissioning. And the high average incidence at age 14 and beyond is due to the fact that the CG-47, CG-48, and CG-49, which were not given many of the newer upgrades, suffered significantly increasing numbers of CASREPs as they approached 14 years of age.

VII. FINDINGS

A. DEPENDENCE OF CG-47 O&S COSTS ON AGE

The O&S costs of the CG-47 fail to show the consistent rise with age that we would expect. Rather, they exhibit a peaking behavior: The average annual O&S cost per ship rose from $25 million to $35 million as the ships approached 8 to 10 years of age, but then fell back to $25 million by age 17, the maximum age of our data.

Because this finding is both important for policy purposes and counter-intuitive, we searched for possible reasons for the peaking phenomenon. None of them proved entirely satisfactory. To help in discussing them, we offer the following simple theoretical picture about the costs of the CG-47s (and possibly other ships as well):

- Large movements in O&S cost, both trends and fluctuations, are mostly due to similar movements in the depot-level maintenance cycle for repair and modernization. These components each comprise about 10% of total O&S, and are both strongly correlated with O&S (coefficients of 0.70 and 0.82, respectively). Unit- or organizational-level costs, although they comprise about 75% of total O&S costs, have been quite stable, both with age and over time, and have only a 0.44 correlation coefficient with total O&S. Intermediate-level maintenance costs, which amount to only 1% of total O&S, have only a 0.05 correlation with total O&S.
- Depot-level maintenance cost is a function of the following:
  - *Intrinsic need for repair*—repairs that, if not made, would eventually leave the ship unable to perform its missions (or require even larger expenditures in the future).
  - *Navy interests in modernization*—to improve the ship's performance either because of an increasing enemy threat, improved defenses against U.S. weapons, or a change in mission.
  - *Entirely separate factors*—the total Navy budget, the total capital value of the U.S. Fleet on which these dollars are spent, competition for these dollars from other needs, and the idiosyncrasies of Navy budgeting.

The first possibility regarding our negative finding as to age is that the fall-off in O&S cost is due to the lower O&S costs of the first five CG-47s—those that reached the oldest age during the period. Those ships lack the more capable Vertical Launch System (VLS) and other block improvements and are used preferentially for less arduous missions, such as drug interdiction and exercises with South America. The O&S costs of these non-VLS ships average only $19 million over the entire period, compared to $35 million for the VLS ships. (In terms of the major components of cost, the non-VLS ships have 35% fewer unit costs, 46% fewer repair costs, and 70% fewer modernization costs than the VLS ships.) However, we found that the O&S costs of the VLS ships also experienced a fall-off at older ages, although less so than all CG-47s taken together.

A second possibility concerns the question of whether the CG-47s might still be too young for age to have taken its toll. This might be the case if older naval surface combatants show a consistent upward trend. However, we found the same peaking behavior when we performed a statistical analysis of all the major surface combatants taken together. The analysis included the older DD-963s and FFG-7s (maximum ages of 24 and 19 years, respectively, by 1999) as well as the newer DDG-51s and CG-47s (maximum ages of 8 and 16 years).

Another possibility relating to repair cost is that Navy maintenance officers might have been cutting back on insurance repairs in response to CNO directives to move from the less frequent CNOavailabilities to the shorter but more frequent TYCOM availabilities. A counter to this, however, is that Surface Force, Atlantic Fleet (SURFLANT), has not found a rise in its emergent spending.

(Another point regarding the young age of the CG-47s: Our analysis of O&S costs fails to find bathtub behavior, at least partly because we did not consider the initial post-shakedown availability costs funded from procurement accounts, Shipbuilding and Conversion, Navy.)

Finally, there is a possibility that appears to be more interesting. According to Rear Admiral Michael Mullen, "Historically what happens is we decommission ships based on their combat systems' obsolescence, not on their hull obsolescence. Statistically, if you look back at cruisers you will see that for those that we didn't modernize, we decommissioned them at about 14 to 17 years."[1] The Navy is not now considering retiring the CG-47s, and has, in fact, set aside $2.1 billion for the major cruiser conversion plan for the CG-47s,[2] it

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1 Without Upgrades, Navy Fears Early Retirement of Aegis Cruisers," in *Inside the Pentagon*, Vol. 16, No. 22, June 1, 2000, p. 12.

2 "Rempt Places Cruiser Conversion Program on Top of Priority List," in *Inside the Navy*, Vol. 14, No. 2, January 15, 2001.

might have been cutting back on CG-47 modernization spending in prior years as a holding position, either in the hope of receiving additional funds for the conversion program or to avoid spending money in the event it has to decommission the ships. (Note that the article referred to in footnote 1 suggests that the Navy was at least considering the option of early retirement.)

If this has, in fact, occurred, the implication is that the peaking of maintenance, and thus total O&S cost, was at least partly caused by the idiosyncrasies of Navy budgeting mentioned previously. Our results do not, therefore, argue against the expectation that intrinsic repair costs must eventually show a consistent rise. While systems such as gas turbines can be fully replaced, it is prohibitively costly to renew distributed ship systems such as hull structure (e.g., fuel and ballast tanks), fluid piping, and electrical cabling.

This suggests that age must eventually take its toll. The principal finding of our study, therefore, is that either (1) there has been no consistent increase in O&S costs with age during the time period of our analysis—perhaps because the CG-47s are not yet old enough—or (2) the effect of aging has been masked by budgeting idiosyncrasies.

Our analysis does, however, suggest that depot maintenance cost (repair plus modernization) should be analyzed further since it is the driving force behind the behavior of total O&S costs.

B. EFFECT OF RECENT CHANGES IN DEPOT-LEVEL MAINTENANCE POLICY ON CG-47 COSTS

Results are mixed on this issue. The expected shift in maintenance costs and time from CNO to TYCOM scheduled availabilities has been accompanied by unexpected increases in total maintenance costs and times. However, such increases do not, by themselves, prove that the new maintenance policies are ineffective.

First, they may not have been implemented to a significant extent. Despite CNO directives, ship operators, and maintenance personnel still have some incentives to do as much work as they can when yard periods occur, and may therefore frustrate, to some extent, the implementation of the policy changes mandated by the CNO.

Second, although Fleet personnel have told us that the policy changes are still in the process of implementation.

Third, it is possible that implementation may have already occurred and saved money to a significant extent, but costs have nevertheless risen on balance because of other factors (i.e., costs may have risen more in the absence of the policy changes). Final evaluation of the maintenance policies must await more time and data.

C. CHANGES IN CG-47 RELIABILITY OVER TIME AND AS A FUNCTION OF AGE

In addition to analyzing trends in O&S costs, we analyzed data on the incidence of ship Casualty Reports (CASREPs) to see how reliability changed over time and as a function of age. (Incidence measures the average number of new reports per ship per year, not the number of actions that are still open.)

We focused on C-3 and C-4 CASREPs, the most serious ones involving major degradation or loss of a primary mission. The effect of age was dramatic: a four-fold increase in average annual incidence per ship from 5 initially to 20 per year by age 15. The trend in calendar time showed a smaller but still significant rise in average annual incidence from approximately 3 in 1987 to 6 per ship per year by 1990, with little change thereafter.

These observations are not inconsistent. The high incidence of the first ships in 1997–99 was diluted by the presence of the later ships.

The rise by age 14 was driven by problems with a relatively small number of equipment types; but the Navy has a well-managed and high-level Top Management Attention–Top Management Issues (TMA-TMI) program to deal with these problems.

D. ADEQUACY OF METRICS FOR ANALYSIS

We believe that the variables we used led to insight into the issues we studied. These data are (1) O&S costs and maintenance times by hull and year from VAMOSC reports and (2) CASREP incidences by severity, hull, and year from the Navy's Inventory Control Point in Mechanicsburg, Pennsylvania.

We do, however, have some suggestions for improving the utility of VAMOSC data. Most of these suggestions are directed at the Navy itself, since the Naval Center for Cost Analysis (NCCA), which maintains VAMOSC, can only report what it receives from its many sources. First, program managers could determine how much of their spending on combat systems is assignable to individual hulls and report these expenditures for incorporation into the VAMOSC Ship Report.

Second, in addition to reporting the start and completion times of each availability, NCCA could consider reporting total down times for maintenance by hull and year. Analysts who use the data would then not have to scrub the data to eliminate the concurrency, as we described previously. Our scrub reduced 1,186 start and completion entries to 477.

Third, the Navy could try to find a way to report private shipyard costs that would avoid revealing the proprietary interests of the yard.

Finally, sources of VAMOSC data could try to report yearly expenditures in addition to obligations, which may take years to be expended. Obligations in current VAMOSC data comprise approximately one-third of all data.

ABBREVIATIONS

CASREP	Casualty Report
CNO	Chief of Naval Operations
COMNAVSURFGRU TWO	Commander, Naval Surface Group Two
COMSURFLANT	Commander, U.S. Surface Forces, Atlantic
EIC	Equipment Identification Code
FY	fiscal year
ICP	Inventory Control Point
IDA	Institute for Defense Analyses
MPN	Military Personnel, Navy
NAVSEA	Naval Sea Systems Command
NCCA	Naval Center for Cost Analysis
O&MN	Operations and Maintenance, Navy
O&S	Operating and Support
OPN	Other Procurement, Navy
OSD	Office of the Secretary of Defense
PM	program manager
PMA	Phased Maintenance Availability
POT&I	Pre-Overhaul Test and Inspection
R&D	Research and Development
RAV	Restricted Availability
ROH	Regular Overhaul
SEMAT	System and Equipment Material Assessment Team
SUPSHIP	Supervisor of Shipbuilding
SURFLANT	Surface Force, Atlantic Fleet
TAV	Technical Availability
TMA-TMI	Top Management Attention–Top Management Issues
TYCOM	Type Commander
VAMOSC	Visibility and Management of Operating and Support Costs
VLS	vertical launch system
WPN	Weapon Procurement, Navy

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14. ABSTRACT
To gain insight into the operating and support costs of major U.S. surface combatants, IDA looked at trends for the CG-47 class cruiser. This paper presents evidence of the dependence of O&S cost on age and explores cost trends over time. Since the major purpose of the trend analysis was to measure the effects of the recent changes in maintenance policy, we discuss the goals of these changes. We also performed a multiple regression analysis to see how O&S costs depend on age and other cost drivers for the CG-47 class and for all the major surface combatants taken together (to see if the dependence of CG-47 on age is due to the young age of the ship class). Finally, the paper contains results of a quantitative analysis of casualty report (CASREP) trends over time. Our principal finding is that for the CG-47 and other combatants as well, O&S costs do not show the consistent increase with ship age we would expect. Also, CASREP incidence is increasing because of a few problem pieces of equipment.

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